TELESCOPE MAKING 2

The magazine *for*, *by*, and *about* telescope makers! Winter 1978

A Compact 6-inch Refractor

What do you do if you happen to have an 8-inch f/18 refractor lens? Well, if you don't want to spend the next few years engaged in the construction of the kind of "precision tonnage" often thought necessary for such an aperture, then keep your mind open to the surprising convenience and light weight that folded refractor designs can offer. After building mine, I feel like shouting to the world: "You can do it — without owning a bank or a machine shop!"

Let's say, for example, that:

1) You want to spend 99 percent of your money on the telescope and only about 1 percent on the mounting;

2) You can keep the telescope indoors and out of the weather;

3) You want to be able to grab the 'scope and its mounting and walk quietly outdoors whenever you wish, and;

4) You are a visual observer, so you don't really need the accurate star-tracking required for photography; all you want is a good solid mount — even a good solid altazimuth mount!

The answers in my case were:

1) You build a folded 8-inch f/18 refractor in a lightweight wooden box, cutting the length from 12 feet to 7 feet by using an optically flat mirror at the back end;

2) After looking in vain for a mounting design that is neither a crude pipe mount nor monstrous, expertly machined, and costly, you throw all the magazines in a corner and build a simple wooden stand. And it doesn't even have azimuth motion — just altitude! This shocks your machinist friends;

3) You cheerfully carry the whole thing outside, roughly aim it at the desired object and slip a small device under the back end of

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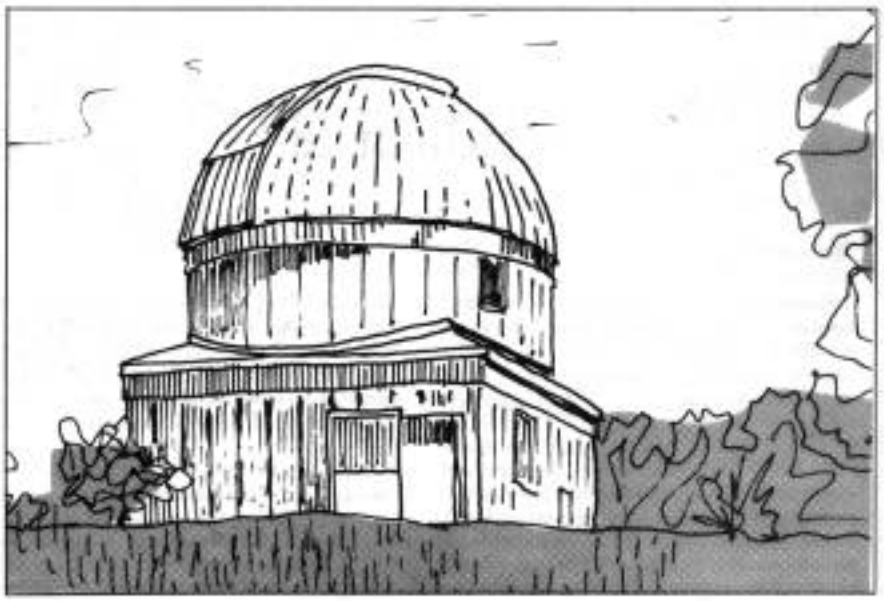

Tularcitos Observatory

"Always build beyond your present needs," is the advice offered to amateur astronomers by Bob Webb, of Carmel, Calif., whose new observatory exemplifies that principle. For example, the slit in the dome is 54" wide, allowing space for a much larger instrument than his home-constructed 18-inch Newtonian now occupying it, and the massive concrete block pier is already capped with a metal base plate to receive a bigger mounting for the next telescope.

The visitor to Tularcitos Observatory, on (appropriately named) Sky Ranch in Upper Carmel Valley, is impressed by the very fine site. At an elevation of over 2,000', the telescope is well above the coastal fog line and clear of most lights. The observatory building stands on a hillock and looks down on all sides to the valley and lower hills. The lot is big enough for a small parking lot, a picnic and barbecue site and a few trees and shrubs that give the observatory a cared-for look.

Upper Carmel Valley is an excellent observing site, affording superb seeing conditions on many nights of the year. The layer of fog which sometimes rolls in from the ocean 20 miles away, stabilizes the air above it, presenting clear, steady images to the telescope user. It is easily accessible — yet well away from the beaten track. It enjoys privacy and no trouble from car lights. A plaque in the observatory records its position: "Lat. 36° 25' 39.1738"; Long. 121° 40' 09.3356"!"

The observatory is a wood-frame structure, stained to match the natural woods used in the area, and makes an attractive addition to the site. It consists of a square-framed room used for living quarters (and eventually as a darkroom) and a circular observing room above. The building, apart from a few specialized jobs, was entirely constructed by Mr. Webb. To keep vibration

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TELESCOPE MAKING

The magazine *for, by* and *about* telescope makers!

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Editorial

Reader reaction and response to the first issue of Telescope Making have been most gratifying, and the staff thanks you for the interest shown in this new publication. After more than 45 years in the field of telescope making, it's exciting to be part of a project for telescope makers that helps them expand their activity and knowledge of optics and observing. I'm proud to be part of an organization that shows its interest and faith in the future of amateur activities and am pleased at the opportunity to be able to continue my efforts in helping others in the field of telescope making as I have been doing for over 20 years.

Many people mention, when approached as a possible source of an article on some project or idea, that they can't write — or feel they can't write — for publication. Nothing is further from the fact; everyone can write and put down ideas. Some people just express themselves better than others. When you send an article to us for publication, you automatically become a teammate of our staff and have its years of publication experience working with you. When needed, we'll collect your thoughts and rearrange them, write more copy if necessary, and send the final version to you for your approval. If you think you can't write, after working with us, you'll think you're another Ernest Hemingway — well, almost another! So there is no excuse now. YOU CAN WRITE. Let us be, if necessary, your teammate in presenting your ideas in TM.

As mentioned in the August 1978 ASTRONOMY, the new designs presented there are being considered for prototyping and field-testing in TM. The article by Robert Sigler in this issue is the first such case. As of last November, two more new designs have been completed and tested and will appear in future issues with full specifications for reader use. Remember: if it's new, noteworthy, innovative, worthwhile, easy-to-construct, and gives good performance, you'll find it in TM!

With the advent of the scientific pocket calculator, many people are trying their skill at optical designing. But optical design isn't as easy as it seems; therefore it will be the policy of TM not to publish any new design until that design has been prototyped and field-tested. This is for the protection of our readers. Let us know, though, if you've got a new design. We may be able to help you to follow it up with testing, but remember that until a working prototype is built, TM can't take the plunge in publishing it!

An occasional new column starting in this issue, "What TMs Want," lists subjects on which we have received requests for articles. If you have anything you would like to see presented in TM, send us a card. If there's enough demand — that is, if other readers also want that kind of information — we'll either list it in a "What TMs Want" column or find someone qualified to write it up. If you think you can supply the expertise for a "What TMs Want" subject, drop us a note with a brief abstract of the proposed article, along with a summary of your experience in the subject.

Sincerely,

Robert E. Cox

Robert E. Cox

A Word from the Editor...

This issue of *TM* is twice as thick as the first issue and, though it won't happen with the next issue, we're sure you'll see another size jump in the future. We've made a number of small changes: The smaller type size lets us get in more, bigger pictures without sacrificing article length. We replaced those little "continued from page — " lines with a simple graphic system of "turn page," "go to," and "from" arrows. We think it looks better and it's simpler too. And we eliminated those stories that trailed on from page to page. All in all, we think you'll like the changes.

We're getting letters from our readers, and articles are coming in too. We've started a couple of new departments, and we're hoping to add a few more in the next couple of issues. One thing in particular I want to draw to your attention is the *TM3* and *TM4* "Call for Papers." We hope to devote about half of each of those issues to special interest topics. These issues have come about from talking to many ATMs, answering reader mail to ASTRONOMY, and just plain thinking about what kinds of information the TM community needs. If you've built a big 'scope, or if you'd like to help beginning astronomy enthusiasts, here's your chance! Of course, we'd like plenty of other articles too, from the humblest tips to the biggest amateur telescope in the world.

Oh, yes — be sure to send pictures too. We prefer 5x7 or 8x10 black and white prints the most, then b&w or color negatives, and color transparencies the least ... but don't let that stop you.

Finally, I want to personally thank each and every person who has offered advice and help in starting *TM*, and especially to thank the authors in this issue. I think every one of these projects and ideas is worthy of careful reading. I've enjoyed working with the authors (usually by mail, of course), and I have tremendous respect for the time and effort they put into preparing their work to share with Bob Cox and myself, and the readers of *TM*.

Sincerely,
Richard Berry

LETTERS

Dear Mr. Berry / Excuse me for disturbing you. I am an active Hungarian amateur astronomer and telescope maker. I have been reading your excellent ASTRONOMY magazine for a long time and I am very impressed. Now, in the September issue of ASTRONOMY I have found a very interesting announcing: your magazine called "Telescope Making." As an active telescope maker I would be very interested in this publication and think it would be useful not only to me but to other Hungarian telescope makers also. So I have a great request: I would be grateful if you could send this magazine free of charge! I know that it is a strange request — but it is the only way for getting this magazine. Unfortunately I can not order it because our laws about money sending are very severe: no private person money sending to any western countries!

Hope you could understand my bad situation and will help me get the magazine regularly — improving the techniques of every Hungarian ATMs! For you kind magazine sending I will write regularly about Hungarian ATM activity, newest results and developments.

Janos Papp
Rakosrendozo MAV allomas
Budapest
H-1142, HUNGARY

Dear Mr. Papp / Your first copy of TM is on its way — free of charge. I trust that your articles and pictures, especially pictures, of amateur telescope making in the MAV, will soon appear in TM.

R. L. B.

Dear Sirs / You've probably noticed the piece of material enclosed in this letter. (I certainly did noticeit -it fell out on my desk with a terrific clang! -Ed.) It is a sample of a family of advanced ceramic materials with demonstrably superior properties to glasses. These materials are all silicon-based non-oxide ceramics. I apologize for the shape of the particular sample I'm sending you (1/4" x 1/8" x 6"), but I'm on vacation now. The material you have is hot-pressed Si_3N_4 — silicon nitride. It is not particularly fragile; it probably made it through the U.S. mails in one piece unless it was purposely hit with a hammer. But I digress....

Currently, to my limited understanding, the reflective elements of telescopes are constructed of low-expansion, high B_2O_3 glasses (Pyrex). Has there been recent research in improving these substrate materials — or eliminating them entirely? The 200-inch reflector (Pyrex), if constructed of the material held in your hand, could have been as rigid and ground to as fine a finish as it now has — but been only one inch thick! Given its density (3.2gm/cm³) such a mirror would weigh less than 2 tons — what does that 200-inch Pyrex disk weigh?

I am a research scientist at Norton Company and have had a hand in developing these materials. They are extremely strong, light, inert, and non-reactive at any temperature a telescope might operate at. A

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What's New?

Beginning with the next issue, this column will bring you a listing of new products of interest to telescope makers. Manufacturers please note that each item will be confined to a brief description and specifications. Listing in this column will in no way constitute an endorsement of the company or product by *TELESCOPE MAKING* or its publisher.

What TMs Want...

In the files of *ASTRONOMY* Magazine, and now collecting at *TM*, are letters asking for telescope making information. If you're a telescope maker and have experience or know-how that you would like to share, the topics listed below are of special interest:

Simple clock drives for portable telescopes;

Grinding machines for mirror-making;

Easy methods for aligning portable telescopes; and

Homemade Foucault and Ronchi testers.

* * * * * *

Please feel free to write us — either Richard Berry (at the Milwaukee office) or Bob Cox, 205 E. Elm, O'Fallon, Mo. 63366. We'll be glad to hear from you.

call for papers call for papers call for papers call for papers call for papers call for papers call for papers call for papers call papers call for papers call for papers call for papers call for papers call for papers call for papers call for papers call for papers for papers call for papers call for papers call for papers call for papers call for papers call for papers call for papers call for papers call for papers

TM3 TM4

Big Telescopes

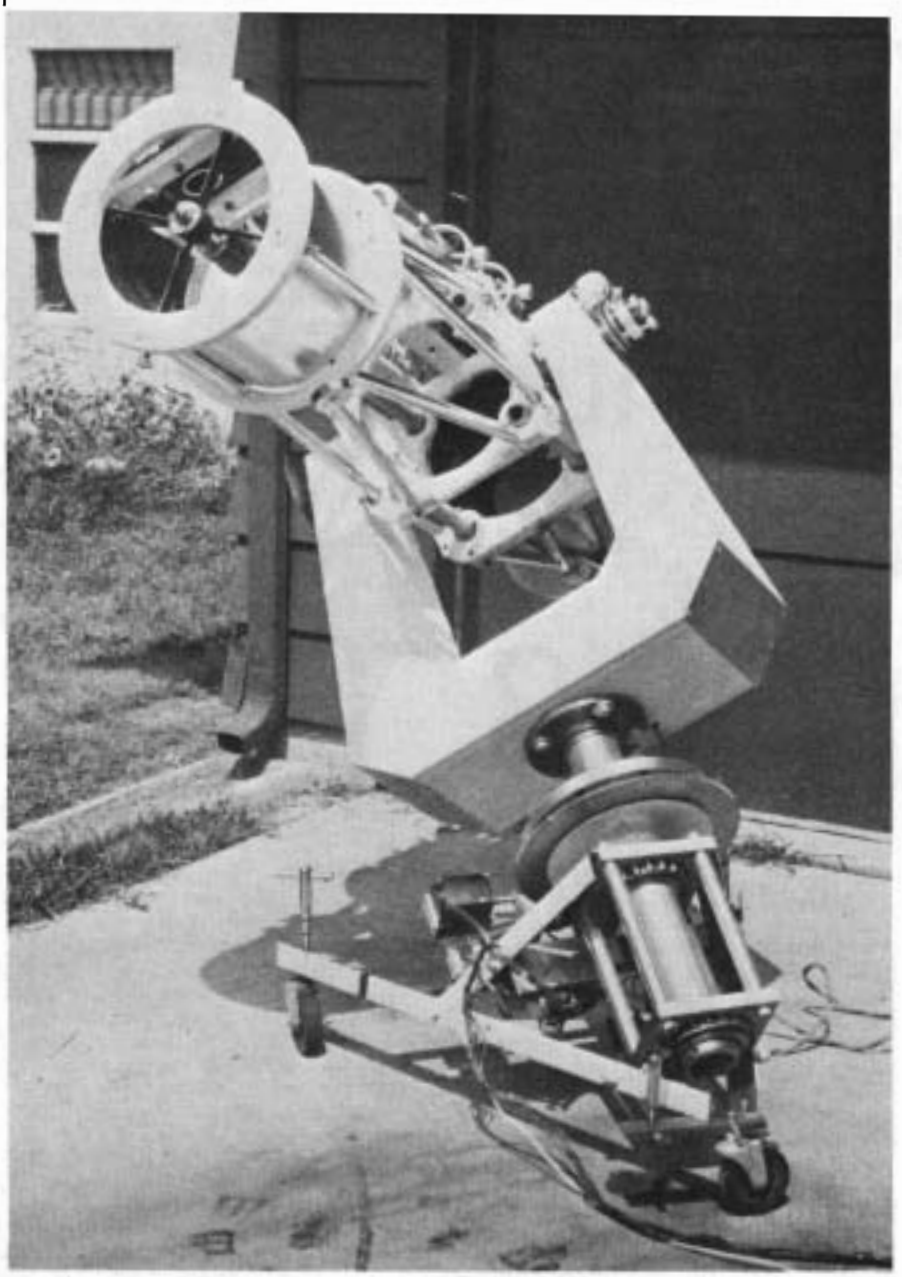
We'd like to hear about big telescopes (telescopes with apertures over 12 inches) whether it's your own telescope or a club telescope, whether it's portable or mounted in an observatory — fancy or plain. How did you solve the particular problems of building a big instrument; what innovations, what standard practices did you follow? We're interested in the mechanical problems you overcame, in the optical problems (including figuring and testing methods) you encountered, and how you housed the instrument. Let us know about your work in words and pictures — and we'll get it into TM3.

Telescopes for Beginners

Building your own telescope is one way — perhaps the very best way — to get started in astronomy. If you're reading *TM*, that's probably how you started. So here's my challenge to you: Design (and build, if possible) a high performance telescope that any beginner could build. Keep the cost as low as possible; keep the components as simple as possible; keep the fabrication techniques as simple as possible; and maximize performance. Submit your design to *TM* by May 1, 1979, and we'll run as many as we have space for in *TM4*. The best design will be written up in one of the fall issues of *ASTRONOMY* where it will reach tens of thousands of people who want a telescope.

A Handsome 10-inch Newtonian

with electric drives on both axes!



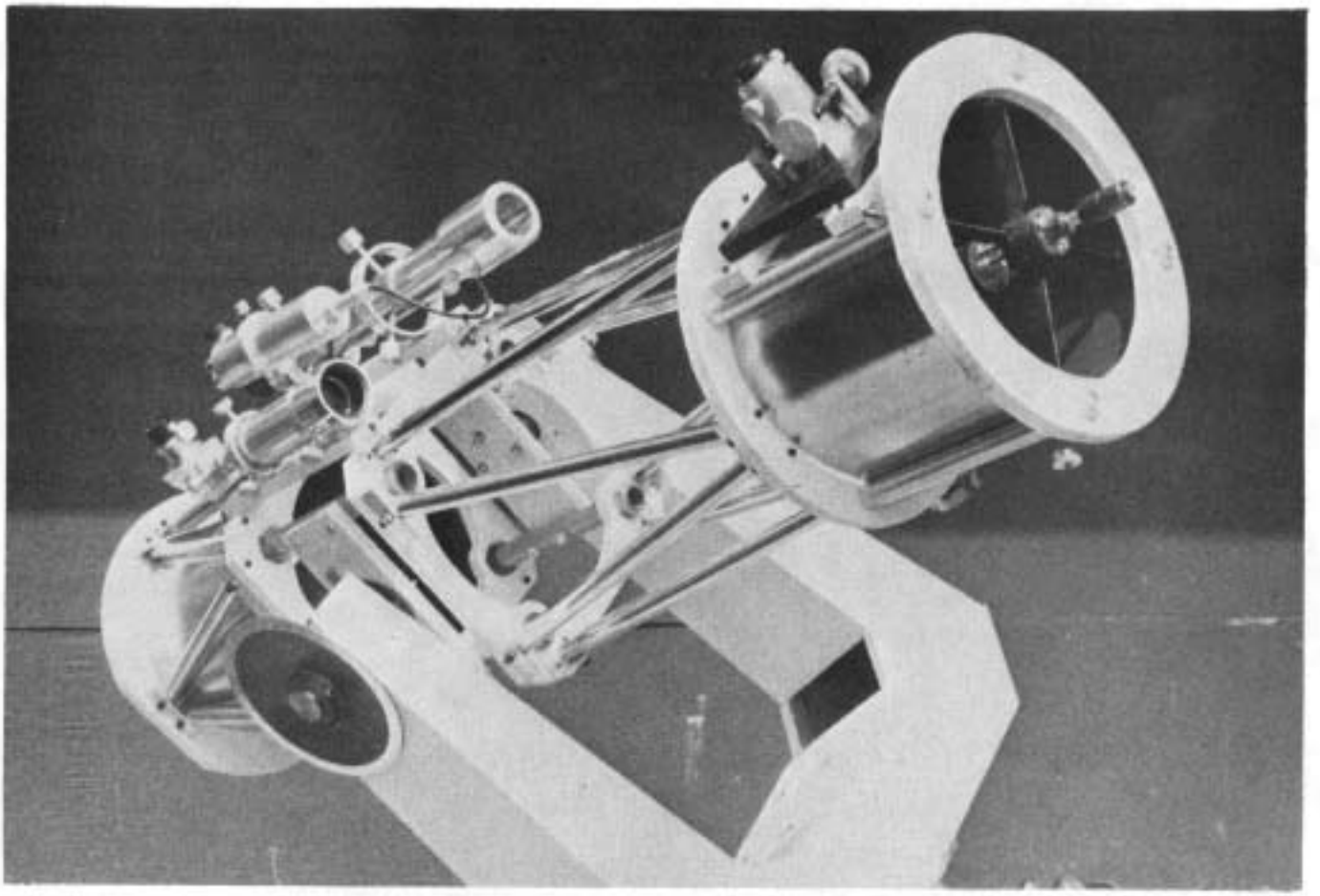
After a search revealed that a 10-inch portable reflector could cost more than $1,500, I decided to undertake the construction of one myself. Although it was my first instrument, I realized that building any telescope is a compromise between weight, strength and size, but I tried my best to find the optimum combination in building mine. Choice of the mirror size was based on the price of commercial optics, especially since I didn't want to grind a big mirror as my first optical experience. Coulter Optical Company produces the least expensive 10-inch mirror of any company I could find — and ordering from them meant I didn't have to spend months and months grinding the mirror.

A first-class mounting for a large reflector is a big engineering project. Since I had no access to machine tools and lacked the know-how to use them, I entered a course in machining offered by the local school system and learned enough to finish the telescope. If you've been dreaming of a really good mount, this is a good approach because you'll probably get extra help and materials — machinists are usually fascinated by the very idea of a powerful telescope!

I chose a fork mount design for astrophotography. With the fork, you don't have to reverse the telescope when it crosses the meridian as you do with German equatorials; furthermore, the fork results in a compact design. I made the fork itself from 3/4" composition board (sometimes called pressboard); one 4'x 8' sheet was enough to do the job, and cost $5.50 versus $65 for an equivalent sheet of 1/4" aluminum. The fork was glued and assembled using over 120 wood screws.

The tube is a truss design chosen for light weight and superior strength. It is made of 1" aluminum tubing, 1"x 1" aluminum angle (both available in hardware stores) and 3/4" composition board. The declination section of the tube is made from 1-1/4" conduit with conduit connector holding the straight sections to the composition board. Composition board sheets bolted to the aluminum tubing support the declination axis assemblies. The primary mirror cell is a conventional design using pressboard, bolts and springs.

The school shop course was invaluable in



making the precision parts of the mounting and the drives. The polar axis uses 3-1/8" I.D. Timkin tapered roller bearings salvaged from a surplus outlet. The bearings were originally intended as differential carrier bearings in semi-trucks, and each has a radial capacity of some 11,000 pounds. The polar axis itself is made of 3-1/8" aluminum tubing with a 1/2" wall. Races for the bearings were machined out of 3/4" plate and are separated by 1" aluminum rods.

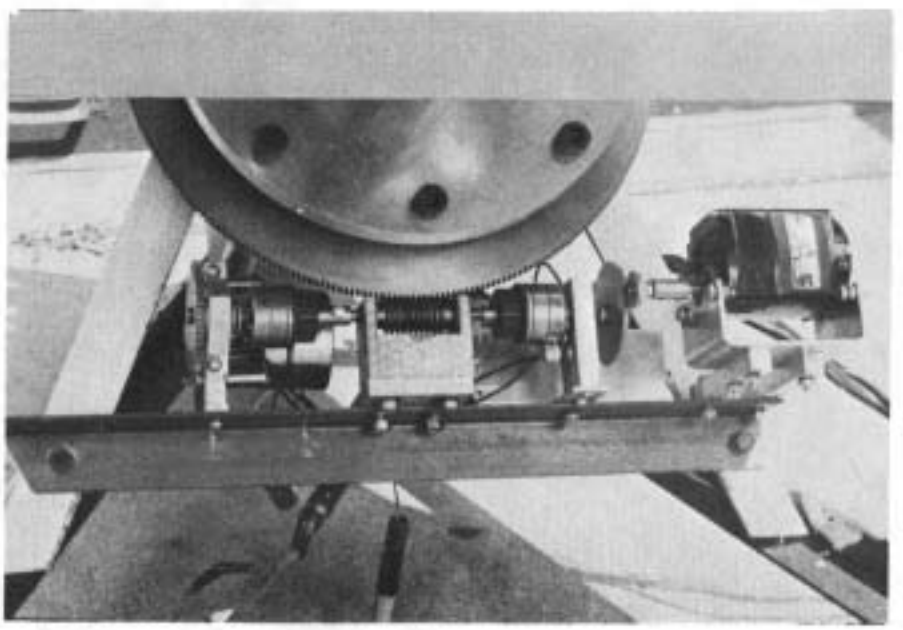
At the top of the polar shaft I used 3-1/2" pipe flanges with reducing adaptors to hold the pressboard fork to the polar axis. The declination bearings are 1-3/4" ball bearings with solid steel shafts inserted into pipe flanges machined to fit the telescope tube. The declination worm and gear are a Browning Gear Works 96-tooth bronze gear and steel worm left over from a previous 6-inch telescope.

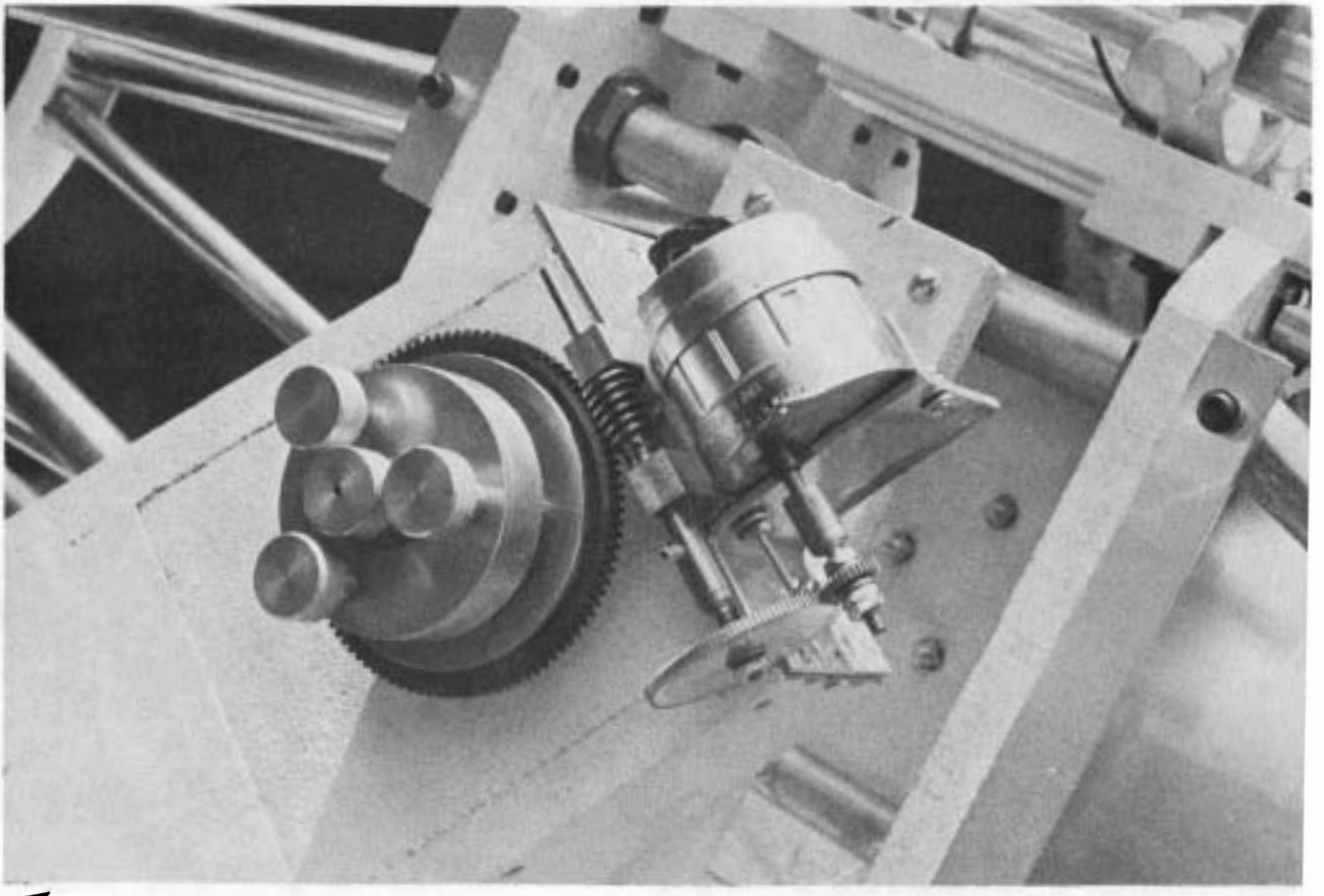
The hardest part of this project, by far, was the drive gear for the polar axis. I had to learn the formulae to cut the 13-1/2" 288-tooth drive gear, and then make the hob out of tool steel. The good part was that all the materials came out of the shop scrap box and cost nothing. The bad part was three gears unfinished and discarded because the formulae were wrong. In all, it took eight months to make the gear, proof perhaps that persistence can triumph in the face of inexperience! The gear is made of cold-rolled steel because the price of aluminum alloy or bronze made those materials out of the question — besides, the steel was free.

The clutch for the polar axis was made of 3/16" plate and a steel tube welded together and machined to fit the shaft. The clutch material is leather.

The drive consists of a 1 r.p.m. Hurst synchronous motor with a 16-tooth gear driving an 80-tooth gear on the worm shaft. The worm drives the main 288-tooth gear through one rotation in 1440 minutes, or once per solar day. Between the worm and the 80-tooth gear on the worm shaft is an electric clutch which disengages the drive motor when the R.A. slew motor is engaged. That motor is a 60 r.p.m. Bodine motor with a 3:1 gear reduction driving the R.A. worm through another electric clutch that engages when the slew motor is activated.

The declination slew motor is a 10 r.p.m. Hurst motor with a 3:1 reduction to the declination worm. Since there is only one motor driving the shaft, no electric clutch is needed. There is a mechanical clutch (a leather washer between two flat plates) so that the tube can be moved by hand.

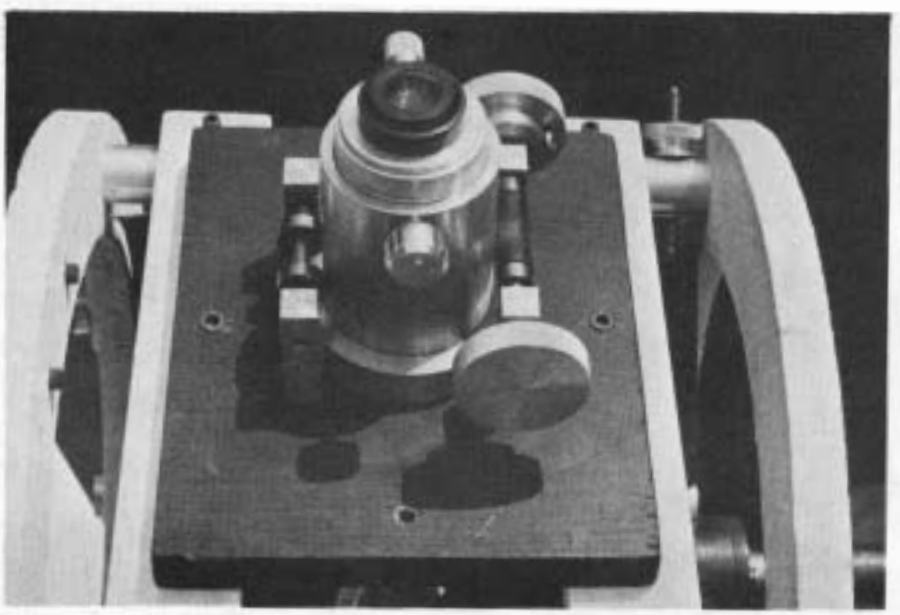




The motors were all purchased from Herbach & Rademan, 401 East Erie Avenue, Philadelphia, Penn. 19134. The Hurst motors were $20 each, the Bodine (used) was $17.50, and the electric clutches $6 each. For an investment of about $75, some spare parts, and a little work, I have drive and slew motors that operate on the same principles as a very large Byers setup. I'm now working on a variable speed drive control using the Saxon circuit (see *Sky & Telescope* , January 1975, page 50).

For the right-angle finder, I'm using a 2-1/8-inch f/10 Jaegers objective and a 75¢ prism from the American Science Center in Chicago. I made the rest of it myself from plexiglas, metal parts, and a spare 1-1/4-inch eyepiece holder. Normally a 40mm eyepiece is best, though the power can be varied by changing eyepieces.

The eyepiece holder for the main telescope is a modified Crayford design using only two ball bearings on a straight shaft on the top; at the bottom a ring around the tube supplies tension and aligns the tube in the assembly. A piece of rubber tubing on the control shaft presses against the eyepiece tube to drive it in focusing. This type of holder eliminates the usual rack and pinion, yet provides smooth and accurate focusing. The holder accepts 2-inch O.D. oculars (including several I've built myself) and an adaptor for 1-1/4-inch eypieces. An adaptor for a 35mm camera can also be used.



Including the shop course tuition, the telescope cost a total of around $350. Considering the cost of a comparable commercially made instrument, it was definitely worth the 2-1/2 years of spare-time effort it took. The entire telescope disassembles into three separate parts for transportation to dark skies, and it can be assembled by two people in about ten minutes. Performance is very good, and the addition of the slew motors makes sweeping an area to find an object a pleasure.

I plan to add a Polaris finder through the center of the polar axis, a rotating eyepiece section, high speed slewing, digital setting circles, and someday — hopefully — computer control when the prices come down a bit.

This telescope was exhibited at the 1978 Apollo Rendezvous and Telescope Fair in Dayton in June, where it won a Certificate of Merit in recognition of the workmanship involved in its fabrication.

Bill Wyant, President
Fort Wayne Astronomical Society
4931 Nassau Drive
Fort Wayne, Ind. 46815

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Accurate Focusing

A recent visit to the Smithsonian Astrophysical Observatory on Mount Hopkins in Arizona, with Professor William Liller of Harvard University, yielded an important insight into the workings of the professional astronomer and his instruments. It proved to this writer that there are useful and easy-to-implement lessons which the amateur can learn from highly sophisticated instrumentation to modify and improve his own equipment.

The first — and most striking — impression which came from merely viewing the magnificent 1.5-meter reflector was that here was a system essentially identical to those built by many amateurs with one principal difference: Where the average reflector at a star party may be in the 8-inch range with a price tag in the high three figures, here was a 60-inch optical giant costing perhaps near a million dollars — certainly so by the time the dome and peripheral equipment were all added to it. Yet the similarities remained once I had overcome an acute case of aperture envy. Seeing how Professor Liller focused this instrument was a revelation which I want to share with fellow amateurs, especially those who, like me, work in astrophotography where critical focusing can make or break any exposure, however carefully or patiently guided.

Rather than turn a focusing knob or twist a dial, an electric motor was used to move the eyepiece in or out at the touch of a button on the hand control unit. Forward and back it went, whining a little as a setting was tried. When the motor moved the ocular forward, a digital readout on a console whirred forward also, presenting a four digit number which rapidly raced from 2040 to 2086. A backward correction reduced the readout down to 2066. Another forward touch produced the number 2073. I was asked to make a note of this number even as Dr. Liller deliberately threw the instrument completely out of focus again, to try a second focusing cycle. Starting at 2020, the readout quickly spurted back to the familiar 2070 and after several short back and forth bursts, came to rest on 2069.

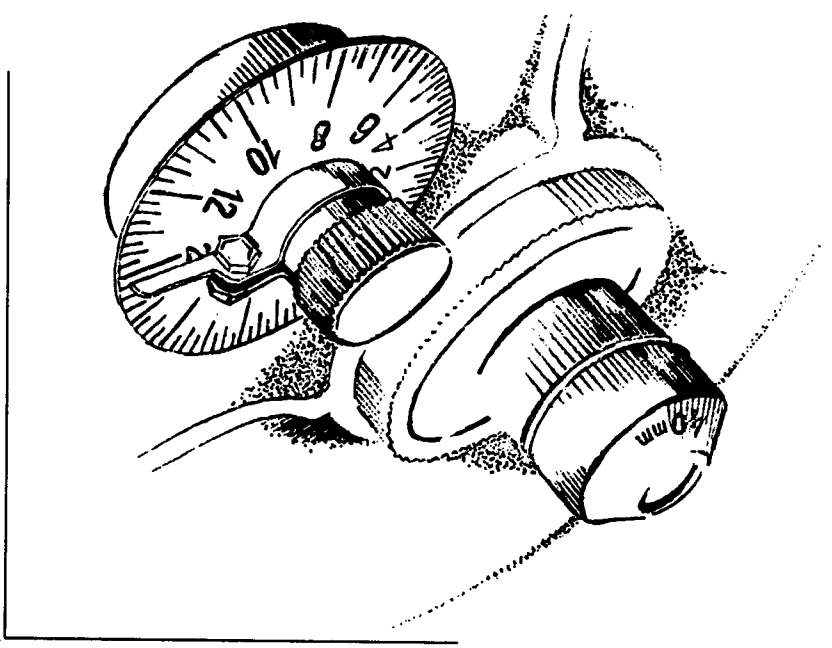
This number also was noted. A third focusing run, this time working down from 3000, quickly homed in on the now familiar high 60s and settled on the number 2068. Adding the three numbers, 2073 plus 2069 plus 2068 equals 6210. Dividing this number by three (the number of focusing tryouts made) yielded 2070 as an average setting. This was the number onto which the telescope was then mechanically focused without further visual checking.

I learned that the four digit number was completely arbitary, its sole purpose being to establish a numerical frame of reference on which an optimum setting based on several visual tryouts could be based.

The rest was easy: What's good for a million-dollar instrument is good for any Celestron, Dynamax, or many Newtonians.

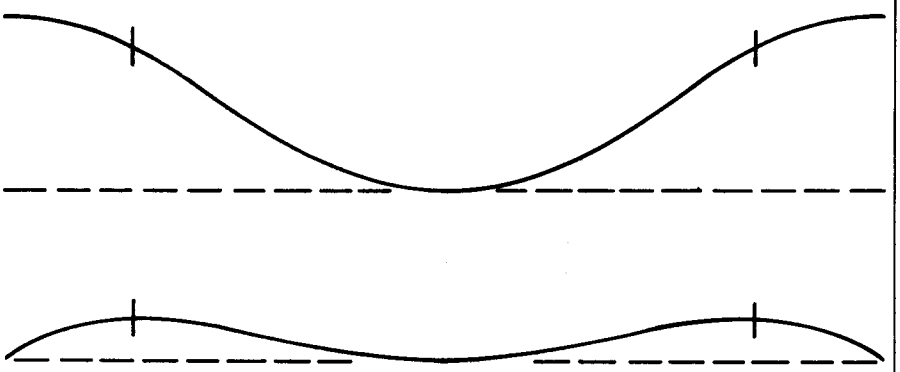
The drawing shows a simple manual counterpart to the costly electric motor focusing drive on Mount Hopkins. A moving pointer attached to the knurled focusing knob and a dial pirated from a broken lamp timer fixed to the scope easily perform the functions of the electronic readout. (The reverse application is possible too, where the dial moves with a focusing knob and the pointer remains fixed.) Since any arbitrary number can serve as a starting point to obtain an average reading taken from different focusing settings, the 48 half-hour divisions on my dial perform extremely well. When attaching any other graduated dial with twin-sided tape to the telescope body, no special position will have to be selected. To focus critically, all I do in my case is to record three arbitrary hour and minute settings and then average them to find my optimum focus.

One important point is worth remembering here: The linkage between the adjusting knob and the movable mirror always has some play in it which can cause focusing inaccuracies when readings are taken on alternate clockwise and counterclockwise adjustments. Therefore, after throwing the instrument deliberately out of focus and when turning the knob for the finer adjustment, always approach your final settings from the same side. I turn mine clockwise — to the right — and I have had the right focus for my photographs ever since.



Ben Mayer
1940 Cotner Avenue
Los Angeles, Calif. 90025

Zonal Test Tolerances



In 1878 Lord Rayleigh established that the theoretical limit of resolution is achieved when a regular aspheric error — meaning one related to one of the conic sections — does not cause a difference in optical path length in the focal plane of more than 1/4 wavelength of light. But because light must traverse an optical error twice, errors in the wavefront are twice as great as surface errors. On the face of it, to have the wavefront error within 1/4 wavelength, it's only necessary to have the mirror's surface accuracy within 1/8 wavelength.

But surface accuracy can be stated in more than one way; one optician may say that he has produced a paraboloid mirror of 1/8 wave accuracy, while another may say the same mirror is accurate to 1/32 wave. Both are honest, but their methods are different. It is useful, therefore, to understand the method Lord Rayleigh had in mind.

A true paraboloid can be shown as a straight line on a chart, with the curve of a smooth error shown as a superimposed wavy line. In the Rayleigh method, only the middle of the straight line is touched by the wavy line, while the greatest separation is at the edge. The slope angle is maximum at the edge and decreases to zero at the center. In the second method, the greatest separation — and zero slope angle — is reached at the 0.7071 zone. From there the curve descends to the edge, reaching maximum slope at the edge of the mirror.

These shapes are what you would see in a knife-edge test using a star as the source. A "donut" with its crest at the 0.7071 zone indicates overcorrection — a hyperboloid. A hollow, or inverse "donut", indicates undercorrection — an ellipsoidal surface. In the Rayleigh method, the chart portrays what is seen with the knife at the intersection of the marginal rays: try to imagine that the crest of the "donut" of a larger hypothetical mirror lies at the edge of the mirror under test. In both cases, the curve always touches the straight line in the middle of the chart. But the error (or departure of the wavy line from the straight line) is four times greater. In most of the following calculations, we'll refer to the case in which the crest of the "donut" is at the 0.7071 zone.

Only regular aspheric errors of curvature — overcorrection or undercorrection — can be easily evaluated through measurement of knife-edge shift. In deriving a simplified

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Eye Safety and Drugs

I recently took advantage of my position as an opthalmic optician to investigate Horace Dall's recommendation in his article "Limitations of Vision with a Telescope" (Amateur Telescope Making — Book Two). In this article he discusses some simple tests that can be done to determine the imperfections in your eye and the condition of your pupil and iris under normal observing conditions. Some methods were suggested for opening the iris to as much as 10 millimeters! This was very appealing to me because I'm a variable star observer and need to make the most of the light gathering power of my instruments.

On page 581 of this article he makes the suggestion that a little belladonna or atrophine could expand the iris to near 10mm, and on page 582 states that if an observer — using one of the great telescopes — put a spot of atropine into his eye and used an eyepiece giving a 10-12mm eyebeam, then the spiral structure of certain nebulae might be "revealed to ocular vision". Then on the following page, Mr. Dall puts forth the suggestion that a "non-injurious pupil dilator" such as atropine or castor oil be applied to the eye before a series of observations.

These statements fascinated me, because if what he said was true, it might give the variable star observer as much as an extra magnitude — and the advantages for the deep sky observer were obvious and exciting. But I couldn't believe this could be accomplished without some penalty, so I consulted both an opthamologist and a surgeon about this practice. Here is what they told me.

Belladonna is a controlled substance today, but it wasn't at the time the book was first published. It's a very dangerous material and should never be handled by anyone who is not a pharmacist or chemist. This substance is stored by the body like many other chemicals, and can reach lethal levels over a period of time! It is extremely dangerous and should not be used for such purposes as Dall recommended. Some non-prescription drugs — especially those for colds and hay fever — contain small amounts of belladonna and those who may be taking them may experience some ease in dilation of the eye from this internal use, but little more.

Dall's suggestion to use castor oil in the eye surprised both doctors and they agreed that it would do nothing to enlarge the iris. One did say that it could transmit disease and/or infection to the eye. (As an aside, there are some diseases of the eye which, though rare, can cause blindness so fast that by the time you realize you have a problem and by the time a physician has diagnosed it, it may be too late!)

Atropine is a controlled material too. Nevertheless, there is a form available without prescription which can be very dangerous to use in the eye because of its uncontrolled strength and purity. If you did, however, manage to obtain some, you would find that it indeed dilates the pupil — for a period of 45 to 47 days!

Based on this information, the best advice I can give you regarding trying to increase your ability to see faint objects by chemically altering the condition of your eye, is not to try! Observing in a dark environment and dark adapting the eyes by means of red goggles with a red filter over any lights is the safest and best way.

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What's My Abrasive?

a guide to abrasives

Telescope making supplies (especially the abrasives used to grind a mirror or lens) come from a variety of suppliers, and different suppliers have different ways of labelling the same things. This can be very confusing when, say, you run out of a certain grade of grit and friends who might have some to spare bought theirs from different suppliers.

Originally, the grit size of abrasives was defined by the size of the screen mesh used in grading. With the use of finer grits and other means of grading, however, this nomenclature was not applicable, so a new system was devised. Professional optical shops and manufacturers adopted the scale of microns (1/1,000 of a millimeter or 0.00003937 inch) as the base figure. Although the micron has been replaced in scientific nomenclature today by the micrometer, publications of abrasive companies still list the abrasives in microns; therefore, until they change, TELESCOPE MAKING will also use the older term.

The accompanying table lists the various standard abrasives available on the market with their size in both thousandths of an inch and in microns. The list will enable you to select similar size grit from various manufacturers while keeping your working methods consistent. For example, if you're using grit screen size 220 from the Carborundum Co. and run out and someone offers you grit from Norton, by looking up the micron size on the table you'll find that you can use grit 240 from Norton, as Carborundum 220 and Norton 240 both have a micron size of 63!

Any abrasive screened by the old method can have considerable variations in grit size. This has been recognized by the Carborundum Co., whose booklet on abrasives lists the various ranges possible. (These are the figures in parentheses for the first two abrasives on our list.) For smoothing abrasives — screen size 320, micron size 31 — our list shows that grits from 60 to 14 microns are possible in the powder grit. The abrasive companies call the 70 micron grit "cobblestones", and unless the large pieces break down quickly and are limited in number, they can cause a light scratch or oversize pit in the grinding. The 14 micron grit is called "sludge"; it is undersized and doesn't cause scratches, but does mix with the standard abrasive and slow down its cutting action. Obviously, you want to have as uniform an abrasive as possible to avoid "wild" light scratches or pits. Professional shops use Microgrit for this reason — their grading system is among the most uniform.

To help establish a uniform nomenclature, TELESCOPE MAKING will print, whenever possible, the micron size of all abrasives.

THE EDITORS

Carborundum (Silicon Carbide): Carborundum Company

Grit	Inches	Microns
46	.014	356 (559-241)
60	.010	254 (406-165)
80	.0065	165 (292-102)
100	.0048	122 (203-63)
120	.004	102 (140-38)
150	.0035	89 (140-38)
180	.003	76 (114-25)
220	.0025	63 (102-20)
240	.002	50 (85-25)
280	.0015	39 (70-19)
320	.0012	31 (60-14)
400	.00087	22 (45-11)
500	.00075	19 (40-10)
600	.00063	16 (35-9)

Aloxite (Emery): Carborundum Company

250	.00098	25 (38-18)
225	.00089	22½ (34½-16)
200	.00079	20 (31½-14)
175	.00069	17½ (28½-11½)
145	.00057	14½ (24½-9½)
125	.00049	12½ (22½-7½)
95	.00037	9½ (17½-5½)
50	.00020	5 (16-2)

Crystolon (Carborundum) and Alundum (Emery): Norton

46	.020	508
60	.016	406
80	.0105	266
100	.0068	173
120	.0056	142
150	.0048	122
180	.0034	86
220	.0026	66
240	.00248	63
280	.00173	44
320	.00126	32
400	.0009	23
500	.00065	16
600	.00031	8

Emery: American Optical

M302	.00087	22
M302½	.00071	18
M303	.00059	15
M303½	.00043	11
M304	.00032	8
M305	.00020	5

Emery: Bausch & Lomb

500	.00126	32
600	.00098	25
750	.00075	19
850	.00067	17
1000	.00061	15½
1200	.00047	12
1600	.00037	9½
2100	.00030	7½
2600	.00024	6

Garnet Powder: Barton Mines

W2	.00098	25
W3	.00079	20
W4	.00063	16
W5	.00055	14
W6	.00047	12
W7	.00039	10
W8	.00031	8
W9	.00024	6
W10	.00020	5
W12	.00016	4

Microgrit: Micro Abrasive Corp.

30	.0012	30
25	.00098	25
20	.00079	20
15	.00059	15
12	.00047	12
9	.00035	9
5	.0002	5
3	.00012	3

Linde Powders: Union Carbide

C-5250	.000039	1
A-5175	.000012	0.3
B-5125	.000004	0.1

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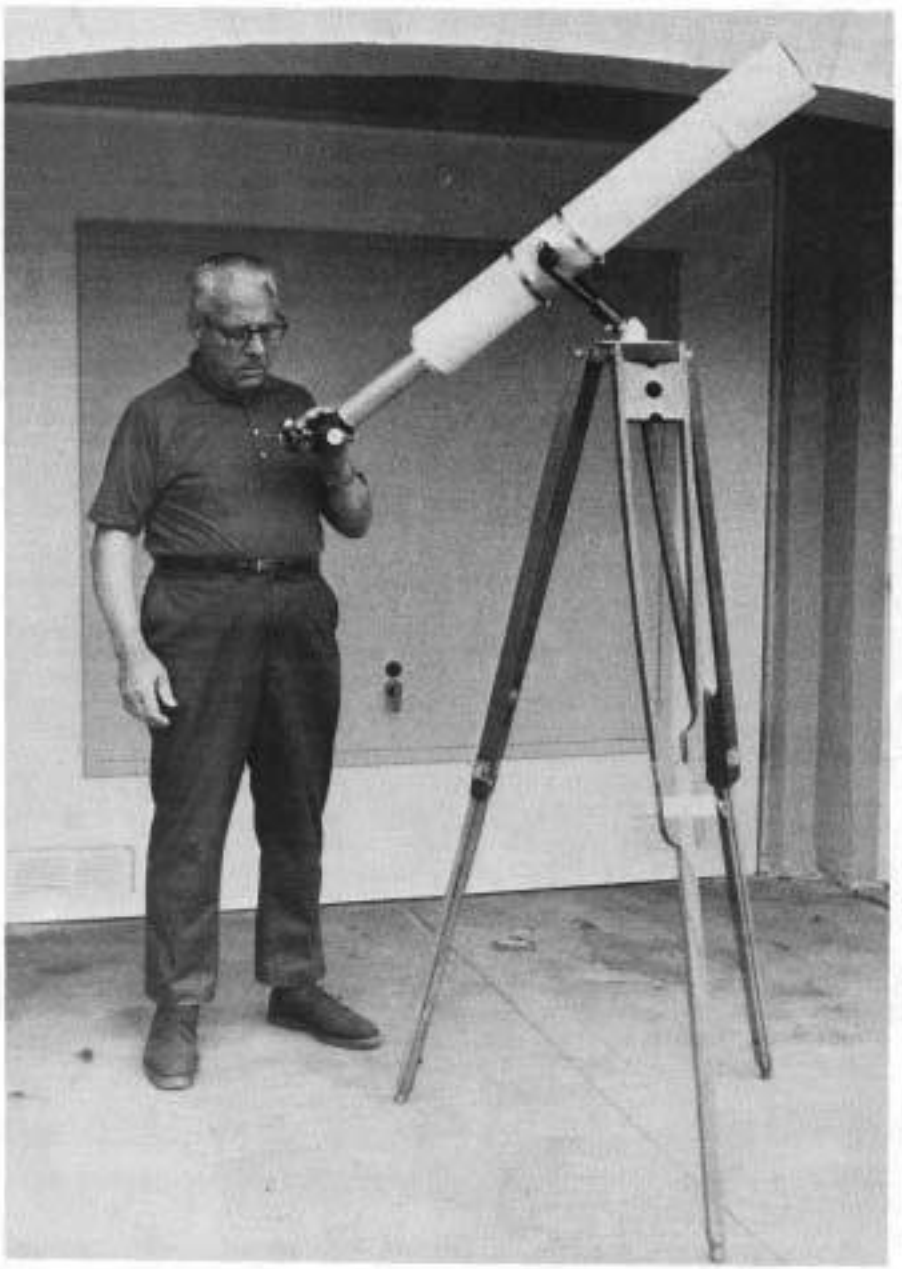
You can travel light with this handy

Tripod Carry Case



Many people have difficulty getting away from city lights. The tripod-telescope carrying case described in this article will take up a minimum of space, making out-of-the-city journeys easier and more enjoyable. You may want to alter this case to fit your particular circumstances. For example, although it was built for a 4-3/8 inch refractor, you might substitute a 6 inch reflector.

Before designing your tripod case, determine how compact you can make your telescope so you can figure the length of the tripod legs. The 4-1/2 inch dew cap on this telescope slides down so just a small rim is extended in front of the objective. At the eyepiece end, part of the drawtube can slide down inside the end plate of the instrument. So, in this case, a leg length of 36 inches was needed to enclose the collapsed assembly.

The tripod head and upper leg spreaders were made from one piece of oak, 1-1/4 inch thick x 4-1/4 inch wide x 30 inches long. Oak was used because it was handy, but any hard seasoned wood can be substituted — mahogany, cedar, etc. If you have metal working facilities, you may want to substitute metal for the parts. No matter what material is used, a wide leg top — where it joins the tripod head — will greatly improve the whole unit's stability.

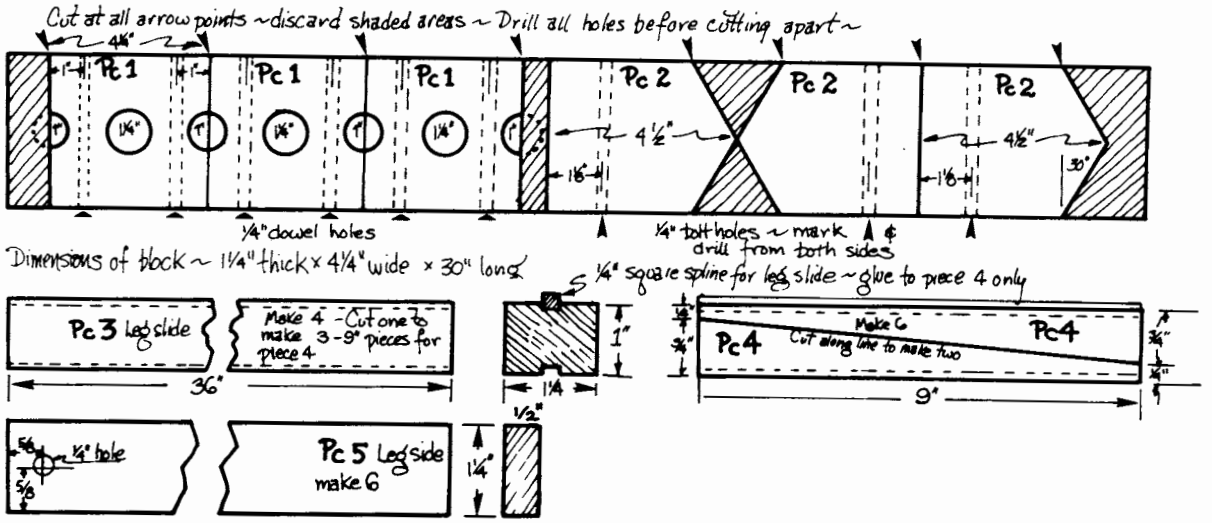
The accompanying drawing shows how to mark all the pieces. Do all drilling before cutting apart the various sections shown on the drawing (pieces #1 and #2). Holes for the hinge bolts should be drilled from each side, because they must be accurate. The dowel holes needn't be as accurate as the hinge (they add strength to the wood), but good workmanship should still prevail. The three pieces which will fit together at the top of the tripod to form the hinges for the legs and three leg spreader pieces will come from this 30 inch length of wood. To hold the

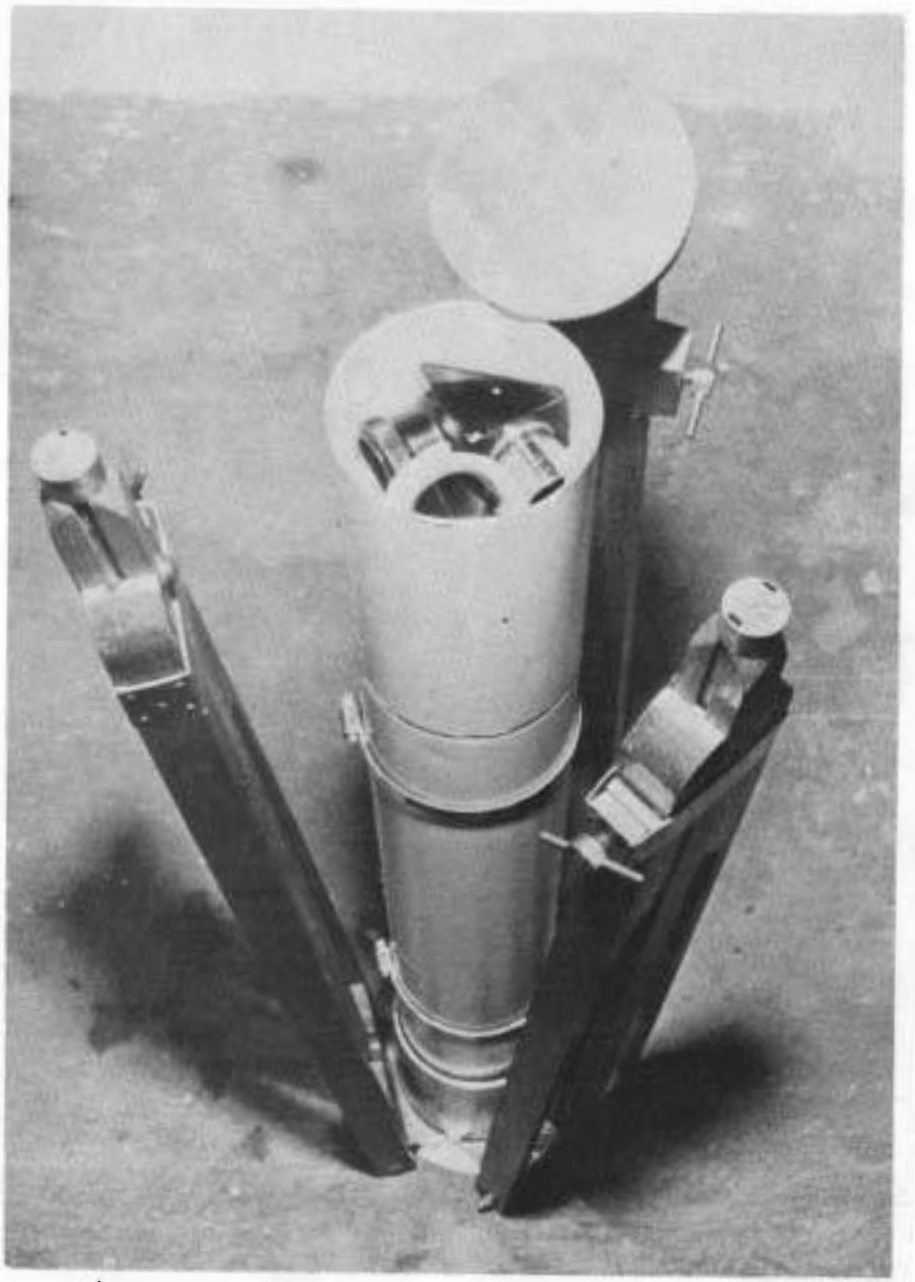
three tripod base pieces together, a 6 inch diameter aluminum plate was screwed on the back of the unit, while on the front, a 3/8 inch deep recess was turned in the wood piece so the outside of the dew cap would fit snugly into this recess (carefully study the pictures shown).

Next make six small leg sides (1/2 x 1-1/4 x 36 inches — piece #5) and four large leg slides (1 x 1-1/4 x 36 inches — piece #3). Each leg slide will have a 1/8 inch deep x 1/4 inch wide groove centered on both of the 1-1/4 inch sides (shown in the drawing). Cut one of the large slides into four pieces 9 inches long. Three of these pieces will be cut to make six #4 pieces. The fourth 9 inch piece will be cut to make six 1/4 inch square splines. Glue them to the six #4 pieces as guides for the leg extensions.

Assemble the tripod head first. Lay it face down on a bench and bolt two leg sides to the top, placing them in a vertical position. Place a leg spacer (piece #1) near the top and clamp it loosely in place. Swing the leg out to the desired angle for the tripod legs — maybe 60 degrees — being sure it clears the leg spacer. Swing back to the vertical and measure the distance from the head block to the leg spacer that was needed for complete clearance. It will probably be between 1/4 and 5/16 inch (see leg assembly drawing, pieces #1 and #2). Make a shim of the determined thickness and place it between the leg top and the leg spacer. The dowel pins inserted in the leg spacer slide in the leg groove and help hold the spacer in position. Glue the leg spacer and legs, and then clamp everything together until the glue is dry. Finally, remove the shim. Carefully done, the final result will be a perfectly uniformly spaced set of tripod legs.

Glue pieces #4 and #5 together. To insure alignment of the parts, use the leg



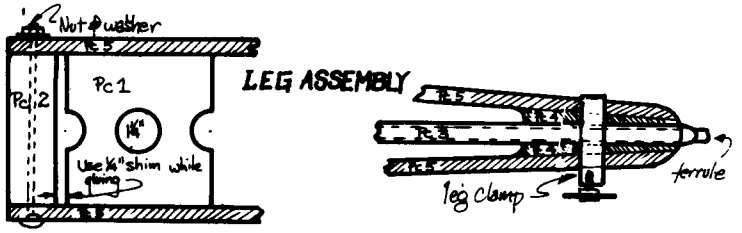


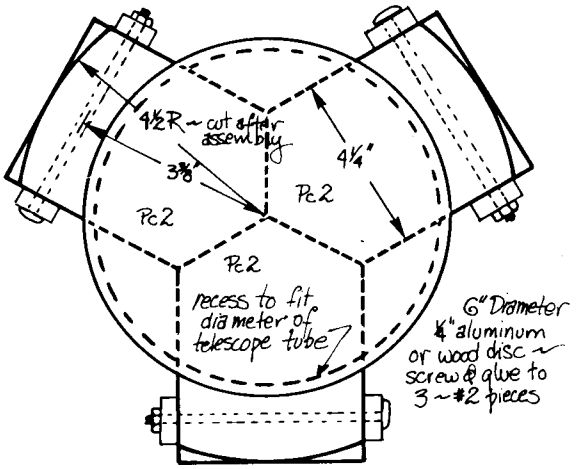
slide to hold the parts in the correct relationship. The tongue and groove arrangement of pieces #3 and #4 will make this part automatically go smoothly.

The sides of the tripod legs are now parallel to the spacer block at the top of the assembly. It will, however, be necessary to force them inward and hold them in position in order to complete the unit. Make leg clamps by bending metal banding — 1 inch wide and about 22 gauge — around a suitable block of metal or wood, and then riveting on the end opposite the clamp screw. I used a 7/8 inch square x 1/2 inch thick aluminum block taped for a 3/8 inch screw to make the clamp nut. To prevent marring the wood with the pressure of the device, make a brass shoe bent up on each end. Place it between the wood and tightening screw. Round the leg slide to a 1/2 inch radius to fit into the half hole in the base of the leg spreader. If you're wondering about the 1-1/4 inch holes in the leg spreaders, they're used to hold an eyepiece — making it convenient to find the next power when observing!

For use as a carrying case, cap the upper end (the eye end) of the telescope with a piece of tube left over from the original construction of the main tube. Remove the star diagonal from the rear of the telescope and place a wooden disk in the spare piece of tubing partway down the tube. Drill four 1-1/4 inch openings in it. The extra eyepieces are put in these openings, then a layer of foam packing, the star diagonal and a final eyepiece. Besides keeping dirt and dust out of the eye end of the telescope, this tube makes a handy carrying case for the accessories. More foam and a wooden disk close off the unit.

To complete the package of tripod and telescope as a carrying case, make a triangular wooden lid. The three openings in it should fit over the ends of





the tripod legs to hold them in position. Felt pads press lightly on the top of the lid carrying the accessories, and a length of cord is used to tie the top down snugly to the clamps on the tripod legs.

The only part of the instrument that doesn't fit in or become part of the carrying case is the fork mount. The fork, in my case, was made from a vacuum cleaner handle. It isn't the most stable mount, but like many commercial mountings, it's adequate for the size instrument it carries. The price was right and most appliance repair shops may have one in their scrap box. The telescope cradle is a piece of aluminum tubing cut down to reduce weight. Its bottom is lined with cork to cushion the tube and prevent it being marred when the telescope is fastened down. Large bands with a screw type tightening unit wrap around the telescope tube and the edge of the cradle to hold the telescope to the mounting.

All my goals for convenience and portability have been achieved in this mounting-cum-carrying case. It can be heartily recommended as a worthwhile project for the hobbyist.

Al W. Daggit
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San Francisco, Calif. 94122

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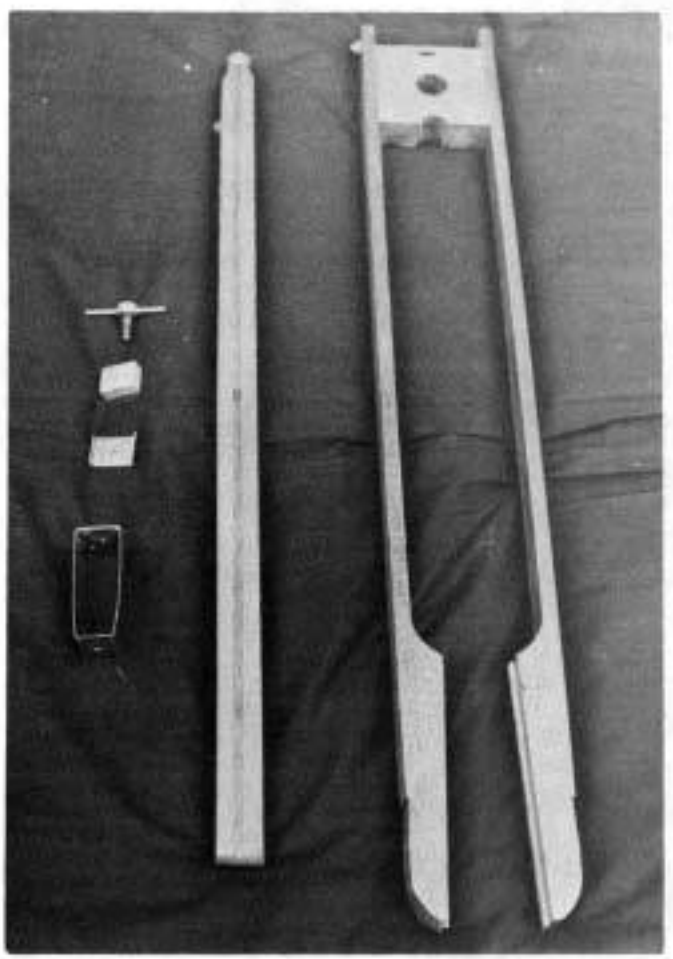

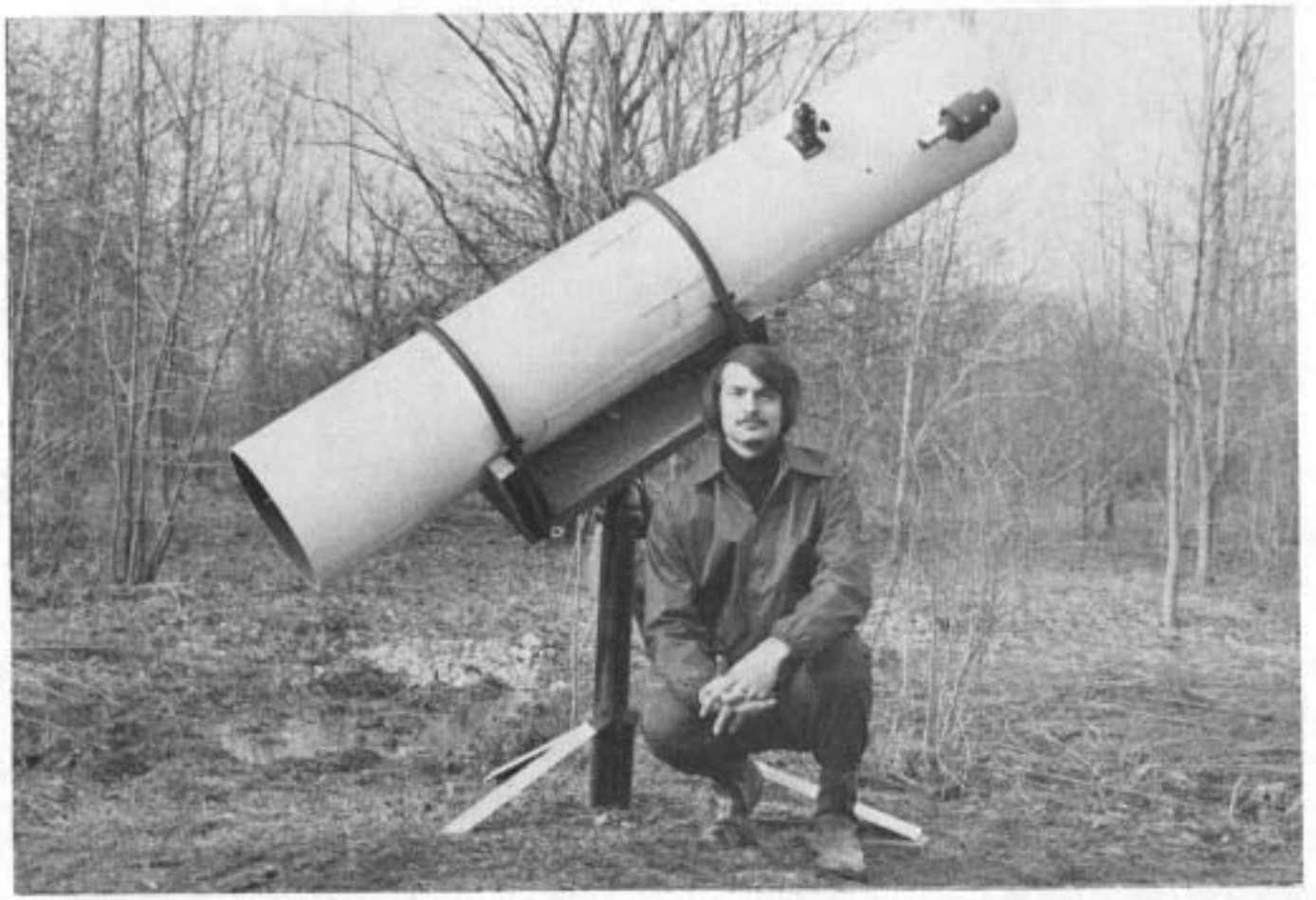

A 14-inch Reflector (that's easy to build...and works well!)

Several years ago, I began observing variable stars with a 6-inch reflecting telescope. Within a few years, I found I needed a larger instrument to study the fainter stars. With this in mind, I set out to build a 14-1/4-inch f/5 Newtonian reflector.

It was necessary that the mounting be simple in design — without circles or drives — and with all the stability expected of a heavy-duty equatorial mounting, yet made of materials available through local merchants.

I decided on a standard German pipe mount using 3.4" industrial pipe, which I hoped would be solid enough to hold the weight of a telescope this large. To provide the 100 pounds of counterweighting needed, the declination axis is reduced to 1" diameter, and the counterweight itself consists of barbell weights. I have found that it's good to lubricate the pipe threads with a mixture of graphite and petroleum jelly. This allows for smooth turning to any position.

Supporting the instrument's pier are three legs made of 1-1/2" angle iron welded to the pier. Each leg extends 36 inches, and they are equally spaced 120 degrees apart. The mount stands 45 inches high to the top of the equatorial head — high enough that the rear end of the tube clears the ground when the telescope is pointed toward the zenith.

After the mount came the construction of the cradle. A set of rings incorporated into the cradle allow the tube to turn, making the eyepiece more accessible. The cradle was built from 2-inch-thick red oak. Oak is excellent for both its strength and beauty. The cradle is 30" long and 22" wide. The sides are 22" wide and 7-1/2" high, with a semicircular section removed for the tube. I covered the wood with several coats of boat varnish to protect it from the wet Ohio weather.

The ring system, which holds the tube tightly against the cradle, is made from garage door cable. To protect the tube, yet hold it firmly, the cable runs through sections of black garden hose. Large eye screws connect the cable directly to the side of the cradle at

one end. At the other, eyebolts and wing nuts passing through eyebolts enable the cable to be tightened over the rings. This mount and cradle are capable of holding a telescope in the 12- to 16-inch range adequately steady.

With the completion of the mount, the tube was the next thing to assemble. It is made from two fiberglass water tanks purchased for $4 each! The ends were cut off with a table saw and each tube cut to a length of 42 inches. Both were then painted flat black inside. The tubes were joined together with steel bars and the seam filled with caulking compound. The outside of the tube was then painted white.

When the optics arrived (primary from Essential Optics and secondary from Coulter Optical), I began assembling the optical system. I constructed a simple mirror cell from 3/4" plywood and coated it with boat varnish.

The cell consists of two plywood disks, one 15" diameter (the inside diameter of the tube), andthe other 14-1/4" diameter. I drilled three holes in each disk and passed a 3/8" inch bolt through each. Heavy duty springs around each bolt separate the disks. Wing nuts at the end of each bolt are used to align the mirror.

The diagonal mirror, or secondary, has a 3.1-inch minor axis. It is supported by a Kenneth Novak holder and spider. I purchased a 2-inch focusing mount from University Optics and installed it on the tube — and the telescope was done.

With this 14-inch telescope, I needed practice again in estimating star magnitudes — there's a big jump in magnitude grasp over a 6-inch! The dimmest star I've been able to see is the 15.0 magnitude star in the Ring nebula; far better than the 12.7 limit for my 6 inch. The new telescope has the light-gathering power of about 1800 human eyes! At 57 power, on a good night, I can see two dust lanes in M-31 and signs of a definite spiral pattern. The entire area around Zeta Orionis is embedded with light and dark nebulae. I have seen the Horsehead nebula, though it is difficult to decide which of the dark nebulae it is.

The complete price of everything came to roughly $600.00. Besides saving a lot of money, I also have the satisfaction of knowing that it is something I have built.

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Build this

All Spherical Relay Telescope

Many of us "telescope nuts" dream of someday building a really large telescope. But a long-focus Newtonian is a mechanical nightmare in a large instrument, and making a short-focus parabola is too much like work! Actually, aspheric surfaces generally don't come out right, at least for me. They're hard to test, tend to take forever to figure, and usually when fully corrected tend to have a somewhat astigmatic surface. Besides, I know from past experience that it's posssible to make a really great sphere! All this suggests that a large telescope should be a Cassegrain or some kind of folded configuration with all spherical surfaces. This is almost always some kind of catadioptric, and unless you are very wealthy, the cost of a 12-inch or larger full-aperture corrector blank for a Maksutov or a Schmidt is prohibitive.

In 1975 Robert Cox sent me Dr. Richard Buchroeder's design for a new simple relay telescope, a design that he had developed and which was awaiting prototype construction and testing (see ASTRONOMY, August 1978, page 37). Mr. Cox asked if I would be interested in seeing if the original design could be modified to eliminate the convex back surface on the secondary Mangin mirror. This would make it easier to figure and test than a flat or concave surface.

Using an IBM 370 computer, I developed the relay telescope specified in the table. The design has both advantages and disadvantages. The advantages are:

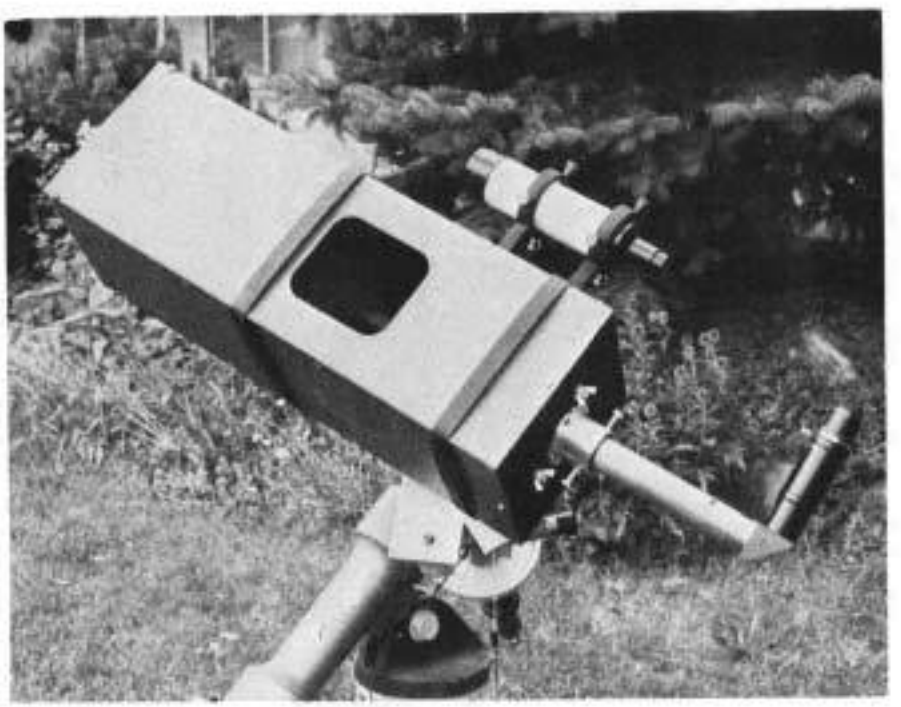
1.) At f/8, it is faster than most Cassegrain systems. Also, its secondary is small, obstructing only 5 percent by area.

2.) All the surfaces are spherical and all refractive components are made from the same glass type (BK-7 or BSC-2, a common low-cost borosilicate crown).

3.) All the surfaces of the refractive elements are either flat or have the same radius, differing only in sign. They can be worked and optically tested against each other using the optical contact or Newton's ring test. This is especially helpful in making convex surfaces.

4.) Although refractive elements are used, the color correction is almost perfect. Secondary spectrum and lateral color are almost eliminated.

5.) The image is erect and an internal glare stop eliminates the need for awkward baffling.



The disadvantages are:

1.) The residual third order astigmatism in this design is not small. It limits the telescope's field of view to 20 minutes of arc, with an overall correction similar to a Dall-Kirkham design. The full moon might fit in the field nicely, but that's about it! The axial image, however, is diffraction limited.

2.) The distance from the primary mirror to the final image surface is rather large. If a star diagonal is used — as it commonly is — then this should cause no trouble.

3.) Because simple lenses image the entrance pupil on the glare stop to eliminate sky flooding, there is a ring of color around the edge of the field of view of the telescope. This color ring could be eliminated with a simple field stop either ahead of or within the ocular.

Disadvantages #1 and #3 are minimized when the telescope is large because then the 1/2-degree field becomes larger — in the physical sense — as a result of simple scaling. Furthermore, because common eyepieces are limited to 1 or 2 inches aperture, in a large telescope with a normal eyepiece, the observer cannot see the color fringe since it falls outside the ocular stop. With a larger aperture, the curvature of field radius also becomes longer, and the ocular therefore delivers a better image.

Since the Mangin mirror has a flat rear surface, Bob Cox pointed out that it can be "unfolded" by doubling the thickness and directing the light out of the tube like a Newtonian. In this modification, the final focus is near the primary mirror. Such an optical system does not require a hole in the primary mirror — a definite advantage in fabrication.

The tolerances on the surfaces of this telescope are really quite forgiving. The radii should be within a percent or so of the specified radii, as should the lens thicknesses, and all surfaces should be good smooth spheres — especially the mirror surfaces. The flat surface of the Mangin mirror need not be

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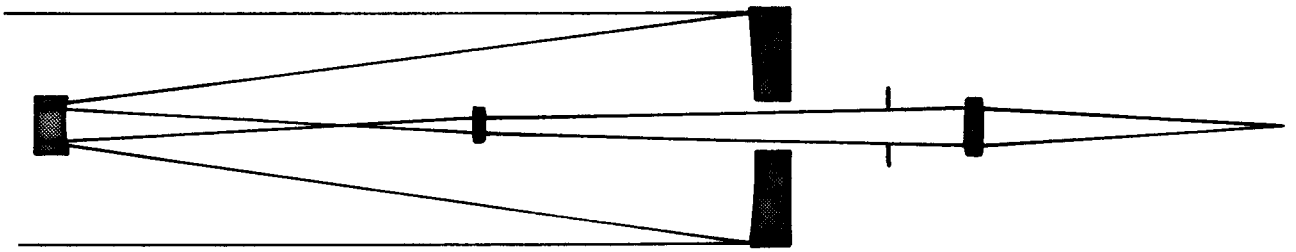
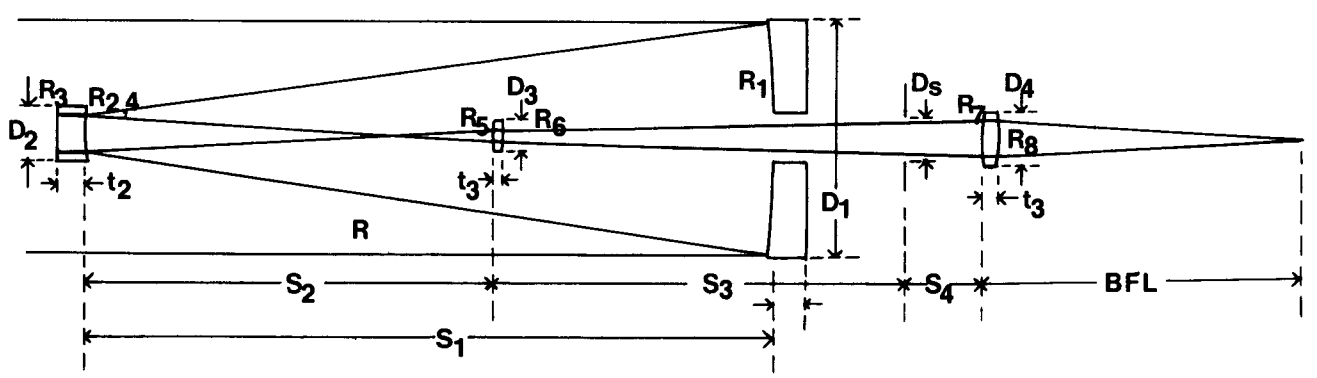


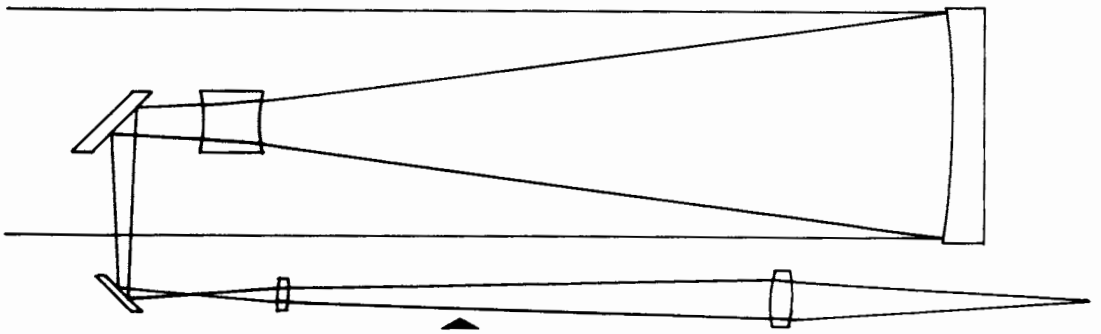
This optical layout of the Sigler relay telescope is drawn to scale. Note that a real image of the Mangin secondary is formed at the stop; the stop limits light reaching the focal plane to just that from the secondary.

Specifications for the Sigler Relay Telescope

System Parameters		**10.0**	**12.5**	**16.0**
Effective Focal Length	EFL	78.826	98.533	126.122
Focal Ratio	f/	7.9	7.9	7.9
Primary Mirror - Pyrex				
Diameter	D1	10.0	12.5	16.0
Thickness	t1	1.7	2.0	16.0
Radius of Mirror	R1	-68.943	-86.179	-110.309
Focal Length	F	34.472	43.090	55.155
Distance to Secondary	S1	-28.150	-35.644	-45.240
Mangin Secondary — BK-7 (517645)				
Diameter	D2	2.167	2.709	3.467
Clear Aperture	CA	2.000	2.500	3.200
Radius	R2	8.655	10.819	13.848
Thickness	t2	-1.277	-1.596	-2.043
Radius	R3	flat	flat	flat
Thickness	t3	1.277	1.596	2.043
Radius	R4	8.655	10.819	13.848
Distance to Field Lens	S2	16.815	21.019	26.904

Field Lens — BK-7 (517645)				
Diameter	D3	1.250	1.563	2.000
Clear Aperture	CA	1.100	1.375	1.760
Radius	R5	8.655	10.819	13.848
Thickness	t4	0.417	0.521	0.667
Radius	R6	-8.655	-10.819	-13.848
Distance to Stop	S3	16.692	20.865	26.707
Stop				
Diameter of Stop	Ds	2.017	2.521	3.227
Distance to Relay Lens	S4	3.177	3.971	5.083
Relay Lens — BK-7 (517645)				
Diameter	D4	2.267	2.833	3.627
Clear Aperture	CA	2.117	2.646	3.387
Radius	R7	8.655	10.819	13.848
Thickness	t5	0.732	0.915	1.171
Radius	R8	-8.655	-10.819	-13.848
Back Focal Distance	BFL	12.538	15.673	20.061





Unfolding this relay system around the flat surface of the Mangin mirror is possible in this design. The stop can be eliminated, as no light from the sky reaches the field and relay lenses directly.

perfectly flat; a few rings (Newton's rings) of power will not harm anything as long as it is spherical. Since all the lens surfaces can be contacted against the concave surface of the secondary, there is no reason why they can't also be within a few fringes of one another. Note that a refracting surface is also four times more forgiving of figure errors than a reflecting one.

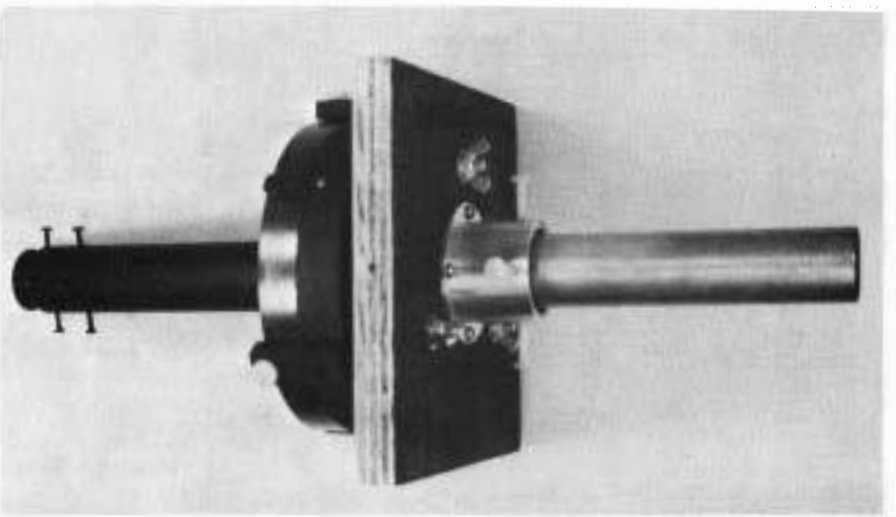
Scaling the design to sizes other than those listed in the table involves nothing more than a straight linear scaling with aperture. However, building this design with an aperture smaller than 10 inches is not recommended. For this relay telescope, the bigger the better!

Building a Prototype

I never did get around to building a prototype of this design, but Bob Cox did. He made the optics, and Jim Wilson of Hazelwood, Mo., mounted them in a square tube. The field and erecting lenses were mounted in a long tube. Standard machining tolerances are sufficient for spacing and centering the lenses. It proved a real advantage to have the angular orientation of the central tube adjustable by a set of push-pull screws located just outside the rear of the tube assembly, so that the tube pivots about the hole in the primary mirror. The tube can also be adjusted along the optical axis by loosening the adjustment screws and sliding the unit toward or away from the secondary.

Several long screws seen in the pictures permit adjustment of the field lens in the prototype; in an actual instrument, they would be almost flush against the metal tube. The hole in the side of the main square tube was also for prototype adjustments. The secondary mirror cell is a standard Cassegrain type with the usual adjustments.

In aligning the telescope, I noticed that secondary tilt errors produced very little color error — only coma. Tube tilt errors produced only color errors and no coma. The color error seen was lateral color. By making use of these distinctions, star images can be adjusted until the image is symmetric with only the possibility of spherical aberration remaining. Spherical aberration is then eliminated by



This relay lens unit and mirror cell permitted quick alignment and testing of the prototype. Screws for adjusting the field lens can be seen sticking out of the tube; the primary is aligned by the wing nuts at the outside of the backplate, and the tilt of the relay lens unit is accomplished by the long bolts extending through the central collar. Jim Wilson designed and constructed these ingenious test parts.

altering the spacing of the optical elements. Spherical aberration is seen as a diference between images a bit inside and outside focus. Work until the two appearances are identical. It sounds complicated, but really only takes a half-hour or so. Furthermore, you won't have to repeat it unless the instrument gets very rough treatment.

The optical quality of the assembled and adjusted telescope was determined using a Fizeau double-pass interferometer — a professional test instrument found in some optical shops. This 12-inch tester has a larger operating cavity which easily accepted the 6-inch telescope for testing. The interferogram of the telescope revealed a maximum departure of 1/10 wavelength for the system. This may not sound great, but it's an honest 1/10 and is much better than any Celestron I have tested this way — there have been several — and is also better than a $1,400 f/4 Tropel collimating lens used in the optical shop,which is claimed to be diffraction limited — and is! I want to emphasize that off-axis, this telescope does not perform as well as the humble classical Cassegrain, and is a touch worse than a Dall-Kirkham.

The prototype, a 6-inch, shows the color fringe around the edges of the field with long-focus eyepieces. Even though the lenses are not anti-reflection coated, the images are sharp and contrasty and, on the planets, all that the atmosphere will allow. In late June Saturn was excellent at 300 power. Despite the prototype's lack of coated optics, no ghost images are seen even on bright objects like Venus. Of course, coating would improve overall light transmission somewhat.

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Editor's Note: I have had the pleasure of knowing Bob Sigler for several years and have been impressed with his interest and enthusiasm in developing improved optical systems for the telescope maker. TM readers are fortunate that, through the interest and efforts of several other professional opticians and designers, it will be possible in the coming issues to present new telescopes that offer either simplicity of fabrication or improved performance or both. Through professional interest and cooperation it is expected that the hobby of making telescopes will reach a new and exciting horizon of instrumentation in the years to come.

R. E. C.

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The Fizeau Interferometer

LENS BLANK GLASS
FOR THE SIGLER
RELAY TELESCOPE

You can order lens blanks for the Sigler relay telescope from Bourns Optical Glass, 2660 Columbia St., Torrence, Calif. 90503, Attention: Elle Davis, by asking for the Sigler Kit #1 (for the 10-inch design) or Sigler Kit #2 (for the 12-1/2-inch design). Each kit consists of three disks of BK-7 fine-annealed grade B optical glass cut to approximate size. The blanks are oversize to permit edging and to allow for stock removal in grinding. The prices quoted are for December 1978, and, because of the fluctuating exchange rate, are approximate. Please write — do not telephone — to obtain current prices.

Sigler Kit #1 (10-inch) — $19.00

Mangin	2.38 dia.	1.46 thick
Field lens	1.27 dia.	1.50 thick
Relay lens	2.30 dia.	0.82 thick

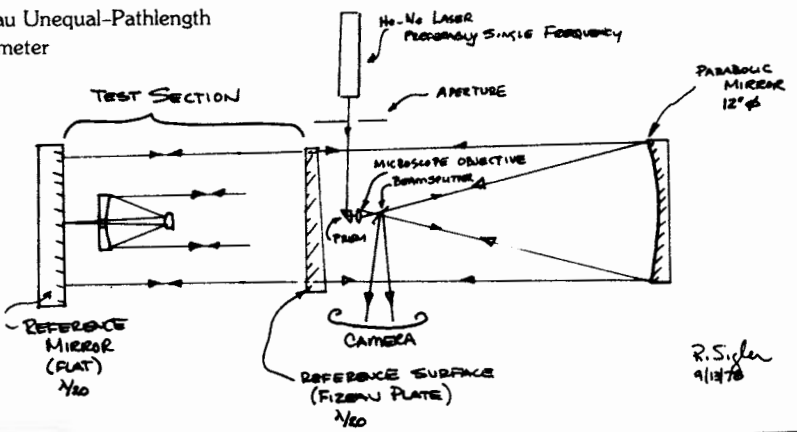
Sigler Kit #2 (12-1/2-inch) — $25.00

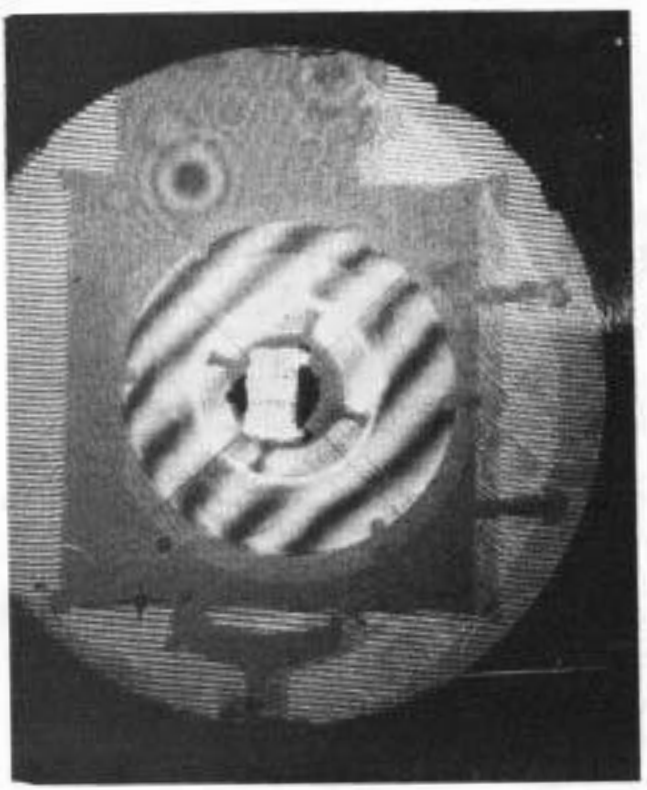
Mangin	2.92 dia.	1.82 thick
Field lens	1.63 dia.	1.88 thick
Relay lens	2.89 dia.	1.02 thick

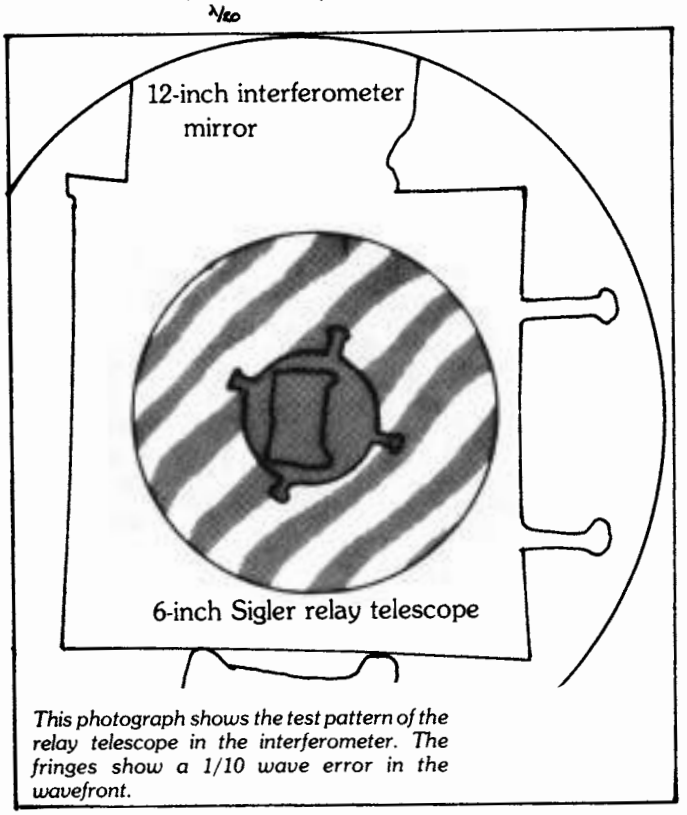
Light from a laser is reduced to a point image by a microscope objective to a point source that expands to fill a 12-inch collimating mirror. The parallel beam then passes through a semireflecting 12-inch Fizeau reference flat (which has a wedge to avoid spurious fringes between its surfaces) and onto a 12-inch reference mirror. Both surfaces are flat to 1/20 wave or better. The optics to be tested are placed between the two reference flats.

Light that does not pass through the test optics travels back through the system to form an image of the source upon itself. Light passing through the test optics has its focus imaged on the surface of the rear flat. After traversing the test optics a second time, it is reflected back through the system to the source. However, the pathlength is longer in the test optics than it is in the outer part of the test region. The wavefronts overlap and interfere, producing fringe patterns which represent the quality of the returning wavefront from the test optics. A beamsplitter directs the interfering wavefronts to the side where they can be photographed or observed on a ground glass screen. ■

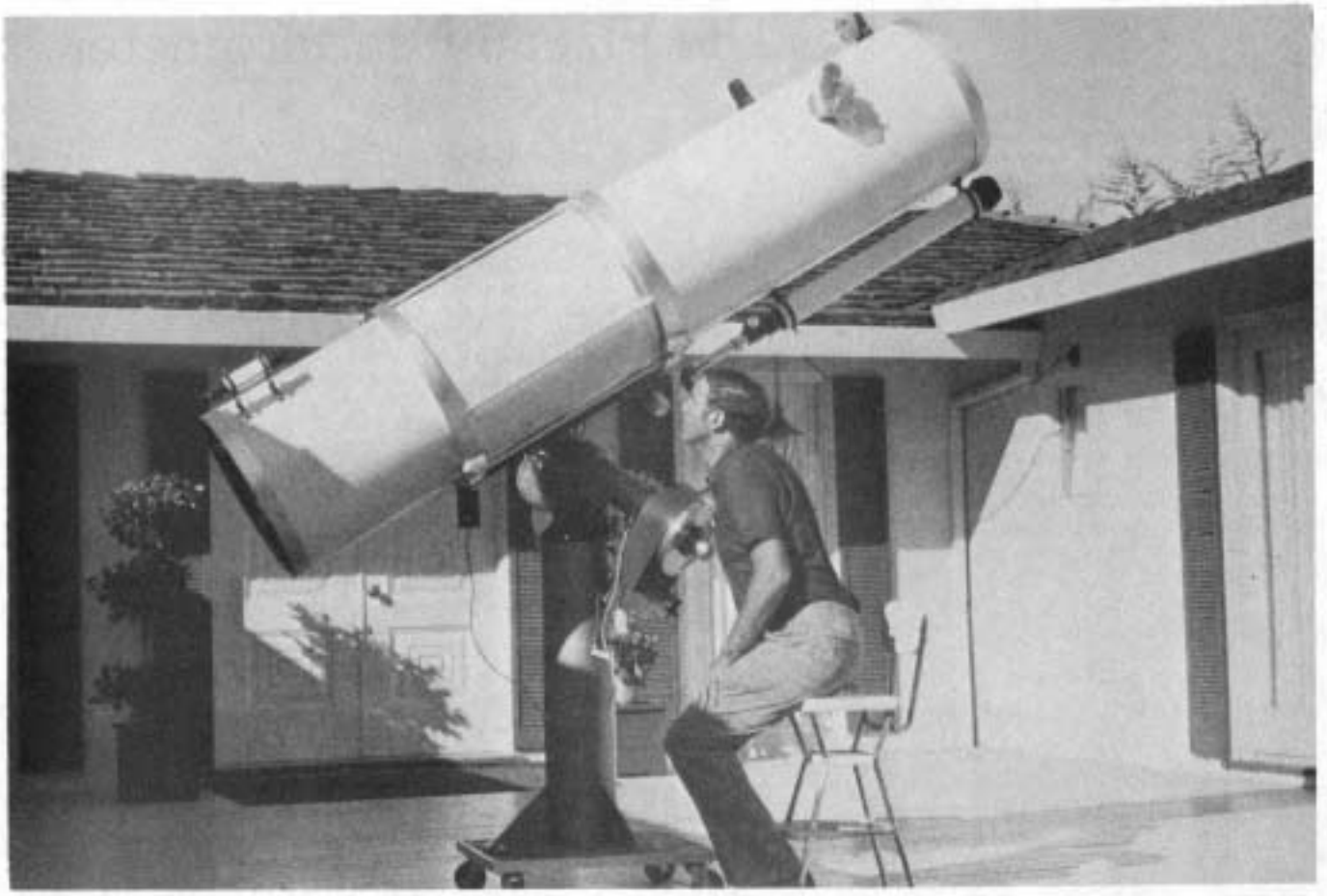
The Fizeau Unequal-Pathlength Interferometer







This photograph shows the test pattern of the relay telescope in the interferometer. The fringes show a 1/10 wave error in the wavefront.



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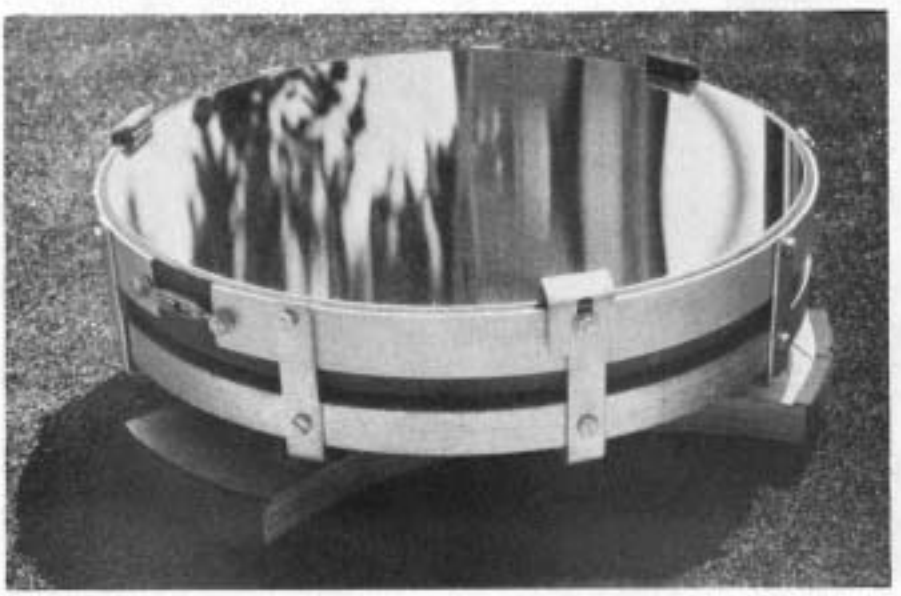
to a minimum, there is no contact between the building and the central pier, which is set on its own concrete foundation beneath the observatory.

Although floors and ceiling are insulated, the building still gets hot in summer. The dome must be opened for about two hours before the interior temperature equals the exterior and air turbulence subsides.

Of course there is a lot of paperwork in building an observatory. Particularly in areas where there are no similar edifices to refer to, as much detail as possible should be included about the structure when presenting plans for local building and zoning approval. The planning officer is interested in structural and engineering details as well as siting, the availability of services, and so on. The suppliers of commercially manufactured domes — at Tularcitos an Ash Dome — will do their best to help out with plans and details of stability.

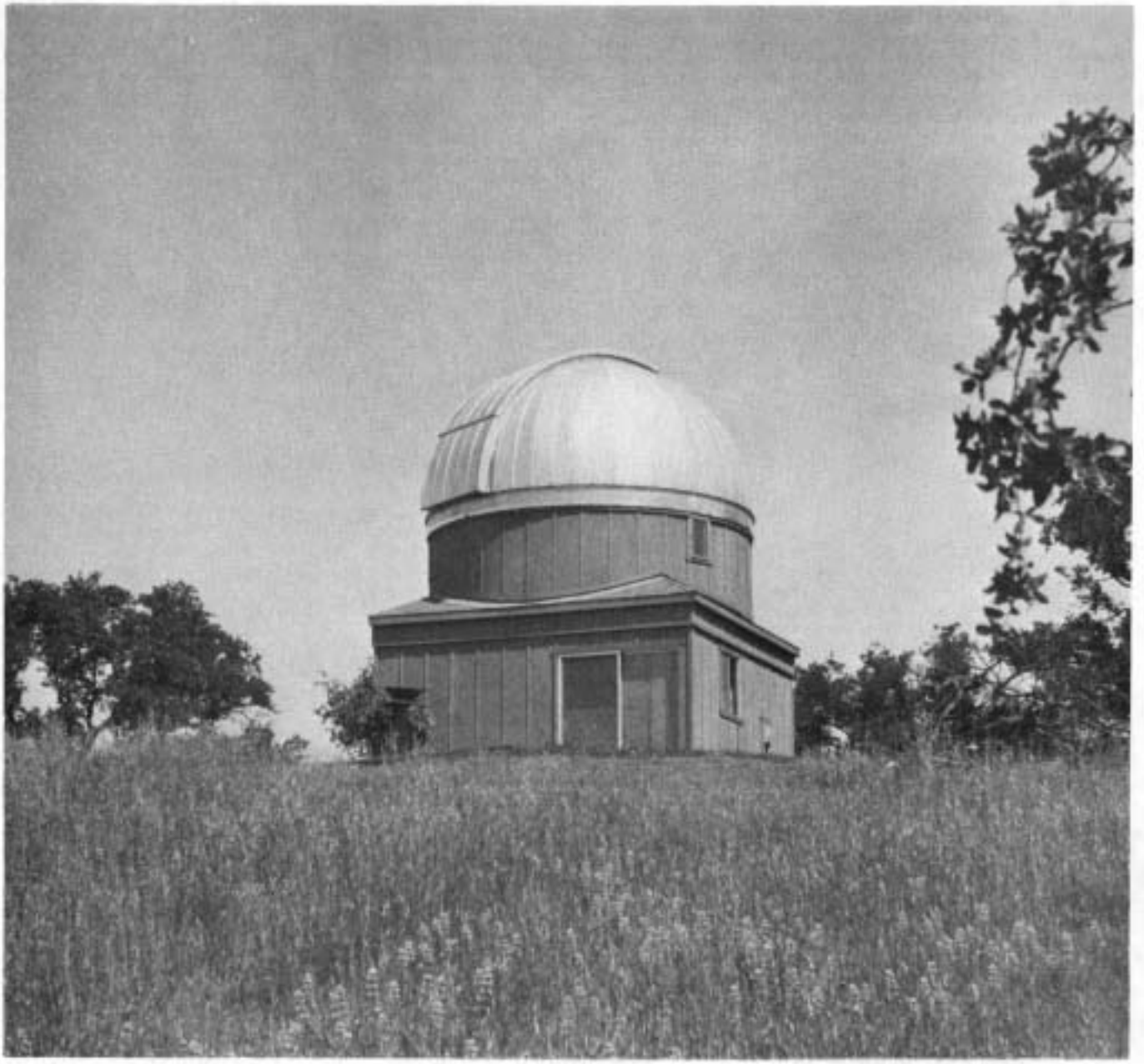
At Mr. Webb's observatory, stability was a particularly tricky problem as the area is subject to high winds. It took some time and visiting back and forth before the county engineers were satisfied; but their confidence in the building was justified in December and January, when winds gusting to 90 m.p.h. made threatening noises around the dome — but failed to damage it.



The observatory is at one end of a small private housing development. Although the houses were few and well spaced out, Mr. Webb was naturally concerned about lights. He was fortunate to get the help of the developer on this — one of the stipulations for home owners is that they restrict outside lighting.

His lifelong interest in astronomy had produced a home-built 8-inch reflector, and when a few years ago he acquired the 18-inch mirror, he decided to buy as many parts as soon as possible to try and offset inflation, even though he did not then feel ready to tackle the construction. However, any amateur astronomer with an 18-inch mirror carefully packed away in the garage will not sleep well at night, so the present telescope, with its massive Cave equatorial mounting and 1/4"-thick fiberglass tube, soon began to take shape.

The f/5 focal ratio of the mirror was chosen so that Mr. Webb could specialize in astrophotography. A longer focal ratio would give a darker field and allow a deeper limiting magnitude for astrophotography, but the f/5 ratio is more suitable for deep-sky photography because faint images such as distant galaxies record on the film within



shorter time exposures, thus relieving somewhat the fatiguing task of carefully guiding the telescope.

The fact that the telescope is a simple Newtonian and has a long tube means that viewing must usually be done from on top of a stepladder. This is an unsatisfactory method with such a large instrument, and Mr. Webb hopes to rebuild it as a convertible Cassegrain so that an eyepiece can also be mounted near the bottom of the tube.

The main telescope tube also carries a small finder and a 3.1-inch (80mm) f/15 refractor for guiding during photography. The Meade refractor is a good instrument which in some applications (splitting double stars on nights with poor seeing) can out-perform the main one.

The main mirror is mounted on an 18-point suspension which can be adjusted by three screws. The flat secondary is held on an unusual spider mount whose three members are curved across the center line of the tube. The idea was to spread out the diffraction pattern more evenly than the spikes of a straight-sided spider. Unfortunately the arrangement is not a success, since the diffraction patterns caused by a conventional spider are less distracting than those of the novel one!

A smooth variable-speed drive from Cave operates the telescope, which is delicately balanced about its mount and can be aimed using either the finders or large setting circles. The 2" rack-and-pinion focusing eyepiece mount is used for a camera as well as eyepieces. Mr. Webb is looking forward to trying a cold camera and hopes to experiment with a plate-holder (as used on professional instruments) before he determines which method he will adopt permanently. Ancillary equipment includes a dual Sidereal/Universal Time clock, a large selection of eyepieces, and a small astronomical library which includes some historic reports issued by Lick Observatory.

For a serious observing program Mr. Webb is looking for a good photoelectric photometer with which to monitor the light of some of the Seyfert-type galaxies believed to have variable nuclei. This time-consuming job is one that can usefully be undertaken with such a telescope and can lead to an accumulation of useful data.

Of equal importance is the use of Tularcitos Observatory to introduce people to astronomy. Small school groups, scouts, and other organizations and individuals are encouraged to visit the observatory where Mr. Webb will introduce them to the use of the telescope. Students with astronomical projects will also be welcome and, of course, so will other amateur astronomers.

The author is a free-lance science writer and is a friend of Mr. Webb.

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A Compact 6-inch Refractor...

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the stand to provide a crank-driven slow motion in azimuth;

4) You observe, using good flat-field eyepieces. The image remains sharp as it drifts across the field, and a quick turn of the crank brings it right back. The mounting, because of its few parts and the huge bearing surfaces at the trunnion, has as much stability as a truly gigantic conventional metal mounting; and

5) You find that your friends like it too — and copy the design!

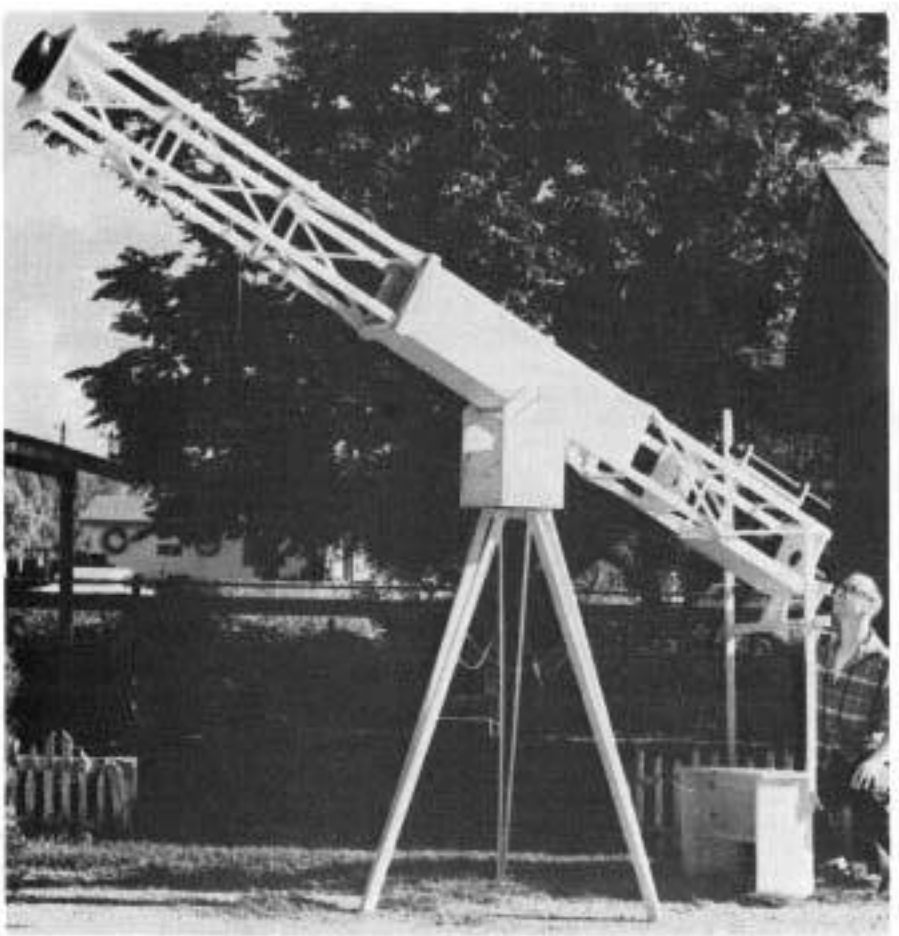
Now for some details. The drawing shows measurements for a 6-inch f/15 refractor built the same way as the 8-inch f/18 — but more readers are likely to have one of the 6-inch lenses. I will happily send the figures for an 8-inch if any reader wishes them.

All the boards are either 1" x 4", 1" x 8", or 1" x 12", sawed — if necessary — to the sizes shown. Threaded rod, 1/4" plywood, and 1/4" and smaller bolts are used as indicated. All joints are glued and then nailed. When drilling the trunnion holes (two in the telescope and two in the stand), drill only three, and mark the fourth with a pencil through the adjacent hole at several telescope positions before drilling the last hole. If you paint or varnish this mounting, take care not to paint the trunnion area of contact in the altitude bearing. Painted of varnished surfaces won't give you the smooth sliding motion that bare wood does.

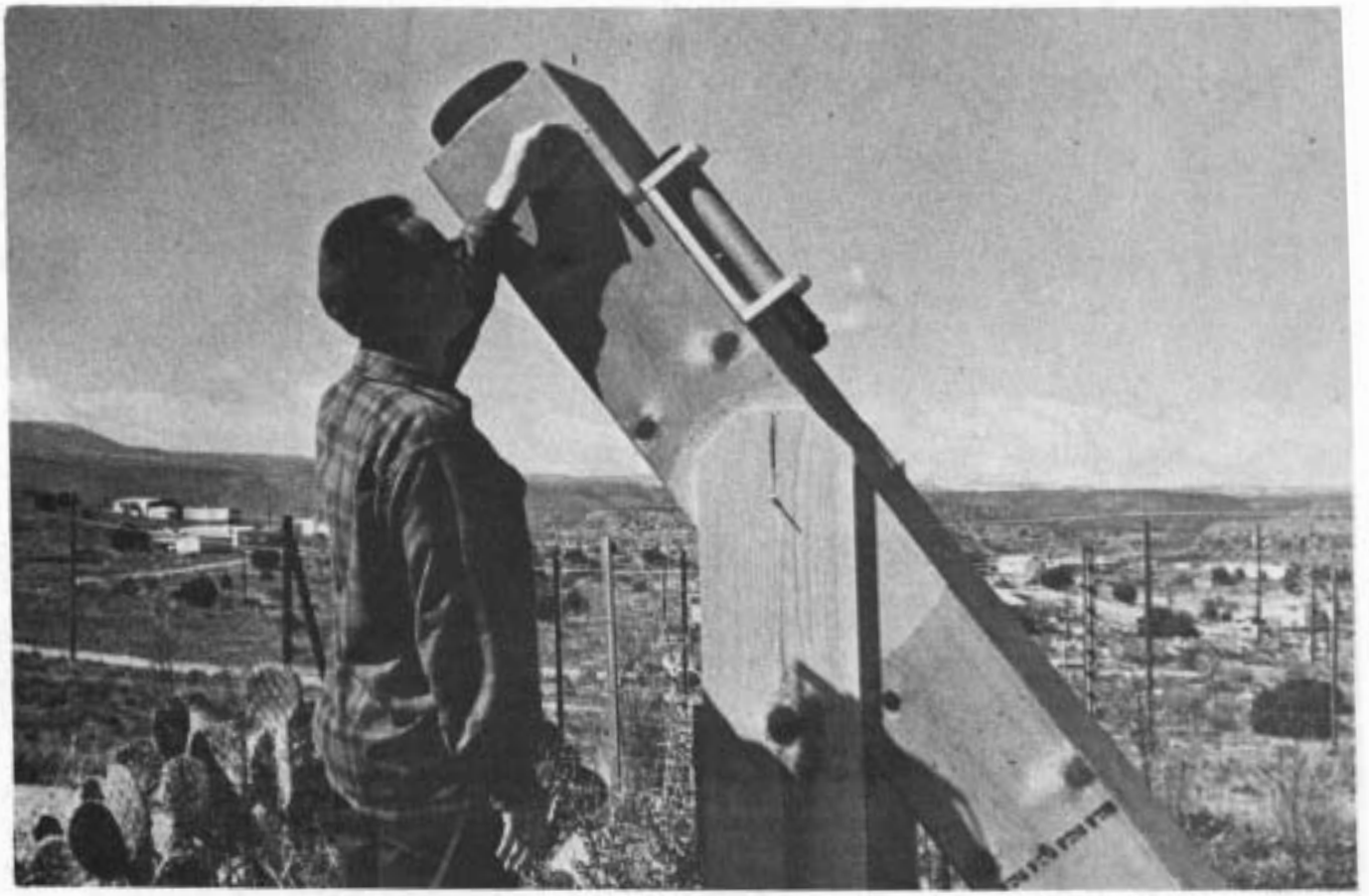
A 4-foot stand like this one will often need a wedge (as shown) for leveling.

The slow motion in azimuth, though simple, works well. It uses a 10-inch-long, 3/8" threaded rod to push the back end of the mounting along the trough. In order to keep the end of the rod from damaging the wood it pushes, either place a block of scrap wood between them or put an acorn nut on the end of the threaded rod.

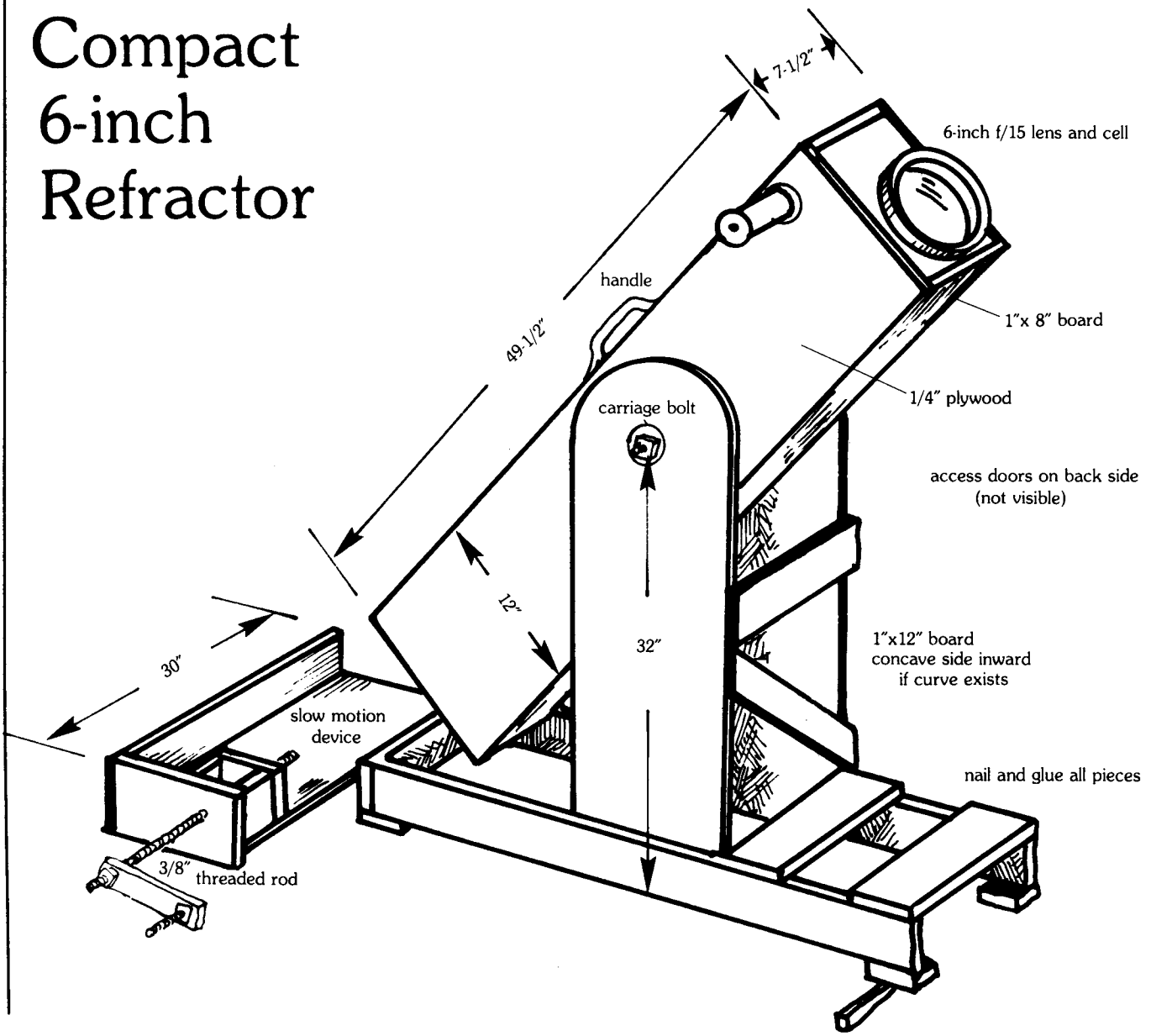
Determining the size of the telescope tube and placement of the optics is easy if you make a scale drawing. You can even work full-scale if you buy a roll of wrapping paper at the dime store. First draw the lens and the cone of light coming to focus. Allow about 1 inch for the size of the focal plane image, then draw the outside edges of the beam from the lens to the focal plane. Determine how far you will place the prism from the plane of focus in the eyepiece holder, and measure this distance toward the lens. Don't forget to allow for focus range, tube thickness or the thickness of the prism. Draw in your prism or diagonal mirror, then fold the entire drawing in half so that the eyepiece end is near the objective. Don't place the eyepiece too close to the front of the tube or your breath might fog the lens while you observe. You might "ghost in" the walls of the tube to help get the best placement. When you have it, firmly crease the paper and transfer the drawing to the bottom sheet. The location of the crease happens to be the location of the folding flat. Measure the size of the light beam to determine the size flat you'll need. ►



Left: The original mounting for the unfolded 8-inch refractor was anything but compact. Top right: The 8-inch refractor in its folded configuration is a convenient size for visual use. Bottom right: Though somewhat cumbersome, the 8-inch refractor is easy enough for one man to carry around.



Compact 6-inch Refractor



Baffles inside the tube strengthen the tube and prevent stray light from bouncing around. In particular, be sure to shield the eyepiece and prism from light coming at large angles through the objective.

The telescope is a joy to use. You simply grab the handle and the back end of the base and carry it outside. The eyepiece is at a convenient height for observing seated in a chair, and of course it's always horizontal! The closed optical system prevents the tube currents and temperature changes so detrimental to most reflector performance (even catadioptrics with thin metal tubes suffer from this). Images are frequently diffraction limited, even on nights when one wouldn't expect it. None of my reflectors resolve so well as this refractor.

Portions of this article appeared originally in the Saguaro Astronomy Club's bulletin.

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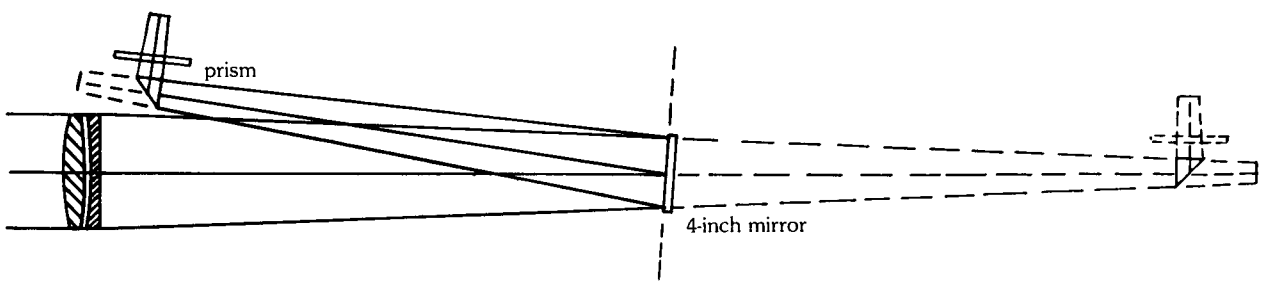
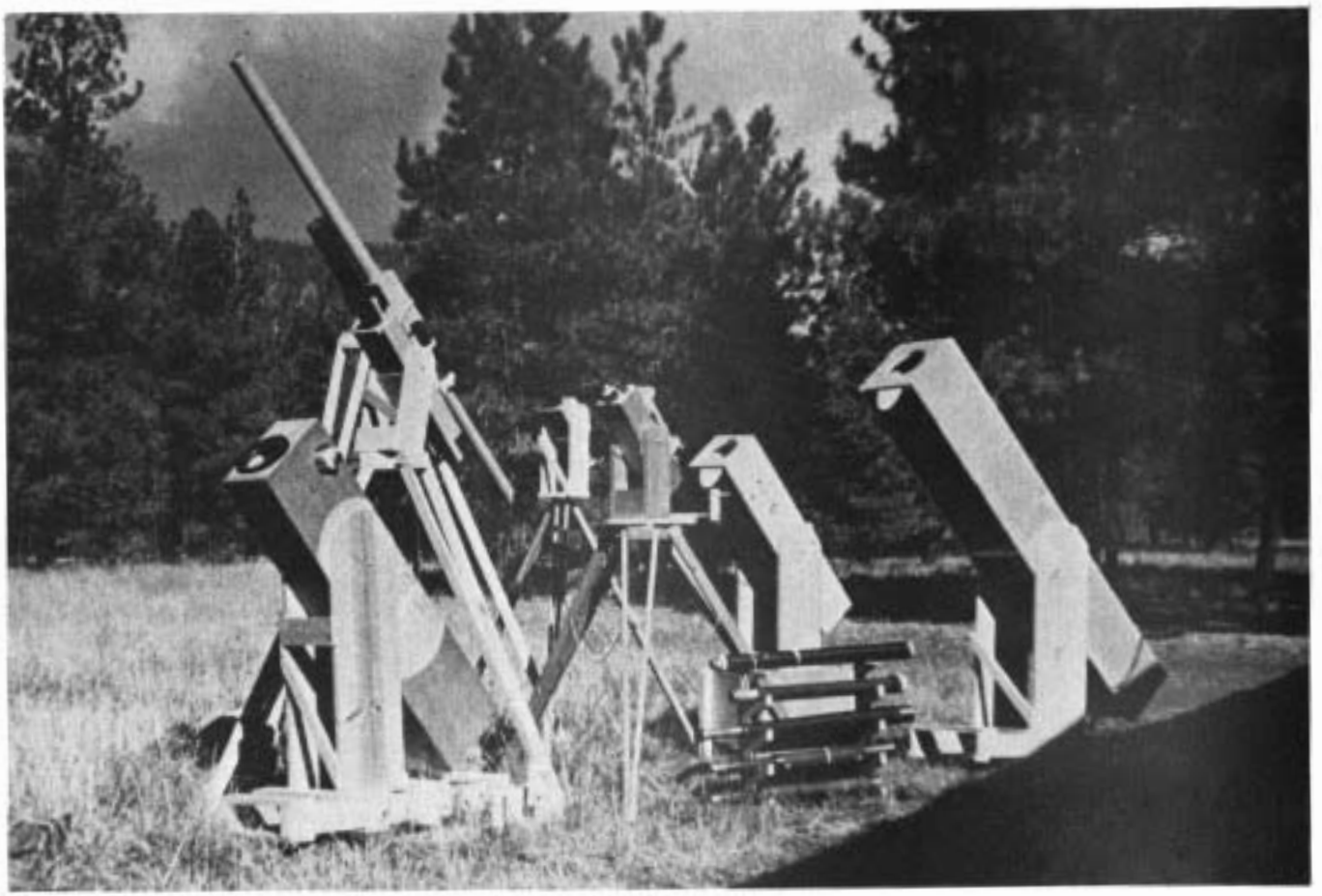
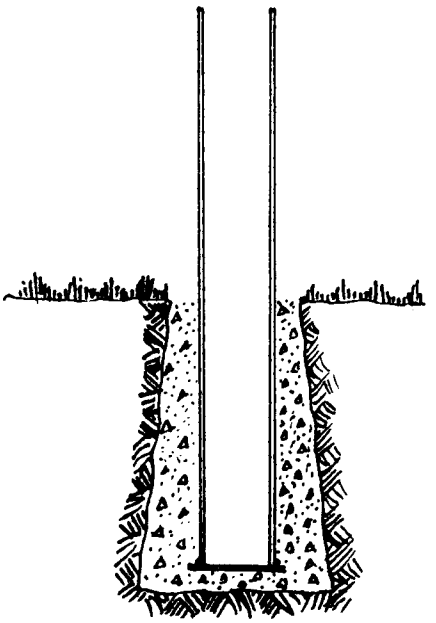




Above: Assorted telescopes, mostly conventional designs; right to left, two unfinished 6-inch reflectors, a short-focus 3-inch refractor with slow-motion azimuth on tripod, 2-inch refractor, long cardboard 1-1/2-inch refractor built in the early style with a single element objective, conventional 3-inch refractor using Edmund parts, and the 6-inch folded refractor. The small telescopes on the rack are antique spyglasses, except the one at the top, which is a homemade demonstrator with quickly removable cardboard lens cells. Right: Stephen Smith and his folded 6-inch refractor. The slow motion device is visible under the back end of the mounting.

Many TMs tend to forget just how useful and convenient alt-azimuth mountings can be. And perhaps because so many amateurs have had very unrewarding experiences with small wiggly alt-az mounts early in their observing careers, many observers are strongly prejudiced against them. But how often have you seen precision portable mountings set up so quickly — without being aligned on the pole — that there was no possibility that it truly functioned as an equatorial mounting? Mr. Smith has shown considerable originality and persistence in developing the simplest of all forms of mounting into an effective and inexpensive alternative for all kinds of telescopes.

Permanent Piers for Backyard



Adequate support and foundation for large telescopes and their sheltering structures is unquestionably a major engineering problem. All anyone has to do to realize this is to stand within the dome of a major telescope and be awestricken. However, there is little carryover of the technical problems to backyard observatories. As the size of the instrument scales down, the support and foundation problem scales down at an even faster rate — but it does not entirely disappear. It seems strange that ATM literature should contain so much information about grinding, polishing and figuring mirrors for small telescopes but practically nothing about the design and making of the pier to support the completed instrument. As a result, some unguided ATMs build piers which are unnecessarily massive, while others — equally unguided — go the other way and come out with "blancmange" supports (as Patrick Moore calls them).

This article will address itself to the problem of permanent piers for reflectors in the 6-inch through 10-inch (aperture) range. When you consider that one man, or at most two, can pick up and carry — albeit somewhat awkwardly — one of the larger sized "portable" instruments, it should be apparent that supporting "all that weight" is a rather piddling engineering problem. Unless you are installing your instrument where soil conditions are particularly bad, there's no need for widespread footings to distribute the weight, nor is there usually any need to carry the pier down to bedrock — in fact, most of the time it would be better to avoid very deep footings.

Some of the principles discussed here may very well be applicable to instruments in the 12-1/2-inch and over class, but installations in that class deserve discussion of local conditions with a competent foundations engineer. One thing should be completely understood: You cannot, by providing a rock steady pier, overcome shimmy which is the result of poor mounting design or construction. All any pier can do is to let a good mounting perform at its potential by providing shake-free support.

Aside from supporting the weight of the telescope and its mounting, the other duty of the pier is that it will not transmit to the mounting any vibrations from the earth. Some of the most troublesome earth vibrations are man-made: from highway and/or railway traffic, from blasting or from other industrial activities. Professional observatories can usually escape these earth tremors — they simply locate far enough away from the source that the vibrations die out before they reach the site, but the amateur, who may be locked into his own backyard, may find them troublesome. You don't necessarily overcome these vibrations by going down to bedrock — in fact, underlying rock strata may transmit traffic vibrations almost unbelievable distances; whereas the hardpan subsoil generally tends to absorb these quivers and damp them out.

If earth tremors are not a problem, a piece of pipe, set in a posthole with properly selected and compacted backfill, makes an entirely adequate pier for telescopes in the 6- to 10-inch range. The depth and shape of the posthole is important. It is important that the hole get well down into the subsoil; how deep to go depends mostly upon the depth of the topsoil. Generally, somewhere in the neighborhood of 3 feet is all the depth you will need.

The shape of a posthole may seem unimportant if you're stringing a fence, but it does warrant some consideration if you're setting a telescope pier. The general tendency is for a hole to taper inward and get smaller as the hole gets deeper, and this is to be avoided. This shape offers the least resistance to frost heaving, for one thing, and in the higher latitudes this is an important consideration. The best shape — by far — is an outward sloping taper. In such a hole, the bottom is larger than the top. This shape does at least two things: It increases the area of the bearing surface of the pier on the bottom of the hole, and it offers maximum resistance to frost heaving. It's a little more bother to dig a hole that way, but the results are worth it.

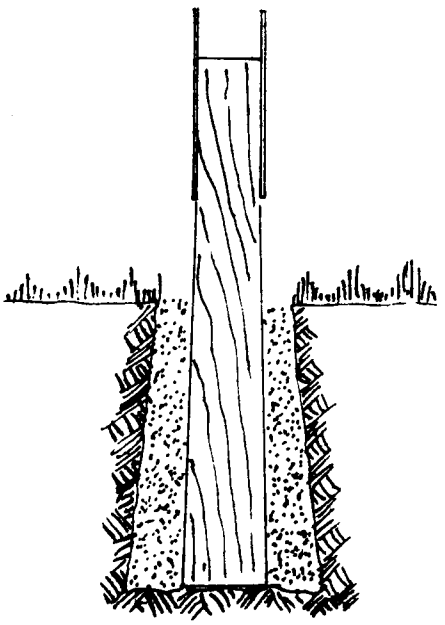
As for backfilling material, there is nothing wrong with using the excavated material, provided you conscientiously compact it in many shallow layers as you fill up the hole, and it is certainly the cheapest. If you don't do the job right, in a few months you'll have a loose or out-of-plumb pier and a situation which is very hard to correct.

Most professional fence builders set their posts in soupy concrete. You don't need a high strength concrete for this job because all you're really after is a non-shrinking backfill with no voids. For a pier, you'd probably do better by lightening up on the water and doing a more thorough job of puddling as you fill the hole up than the fence builders do. It's a lot easier to come out with a good job if you use concrete than it is if you use rammed earth.

Inundated sand makes an excellent backfill, and it has a couple of advantages which ought not be overlooked. It is a practically foolproof method of achieving a no-voids backfill and it also tends to dampen out earth vibrations better than either rammed earth or concrete. You simply pour ordinary mason's sand and water, concurrently, into the hole until it is filled up. There's no tamping or rodding as there is with earth or concrete — just don't try to do the job too fast, and you'll get good results every time.

One of the best places to get a short piece of pipe for your pier is from a fence building contractor. Pipe is made in 20 foot lengths, and a pipe supply house just will not cut it for you. Of course you can prowl around in salvage yards and maybe find what you want, but you may have to settle for used pipe, which may or may not be up to full strength. You'll need a piece somewhere between 5 and 7 feet long, and if you explain your problem to the fencing contractor, he may let you root around in his scrap pile. There is no reason why you couldn't use two short pieces welded together end to end for your pier and if you do find two such pieces, he may sell them to you at the scrap steel price rather than by the foot.

Observatories



You oughtn't settle for anything smaller than the 4" size, even for a 6-inch telescope, and this size will also do for a 10-inch scope, particularly if you fill it with concrete to within 6" from the top. You will find pipe above 4" rather hard to come by: It is so expensive that fence builders don't use it unless there are compelling reasons why the 4" size just will not do. Four inch pipe has another purely incidental advantage: It is the only size which will accept a sleeve coupling of a smaller size without excessive play or without one or the other having to be turned down or bored out. The inside diameter of 4" pipe is 4.026", the outside diameter of a 3" sleeve coupling is 4.000". Thus, the 3" coupling will slip into a 4" pipe with only 0.013" of play all round, and you'll find this a convenient happenstance when you get around to designing the pier head.

If earth vibrations will be a problem, it may be worth your while to consider a composite pier — the lower part treated wood, the top part 4" pipe. A wooden post tends to damp out vibrations whereas steel pipe tends to transmit them. Utility poles are now milled truly round and truly straight and also come in diameters as small as 5". A lot of this kind of material is being used for supporting basketball backstops, and people around here are getting their poles from the local utility department. If you do decide to use such a pier, cut a tenon on the upper end that will accept a 4" pipe. It would probably be difficult to design a pier head that would fasten directly to a wooden cylinder. If you think you will have enough of those earth tremors to warrant using a wooden pier, then by all means use inundated sand as backfill.

The cross sectional area of the end of 4" pipe is only 3.174 square inches. You may be concerned that this relatively small bearing area would result in high unit bearing pressures, causing the end of the pier to cut into the subgrade of the pier hole something like a biscuit cutter. If this worries you, there are two things you can do to reduce this bearing pressure. First, you can fill the lower end of the pipe with concrete. This would increase the bearing area to 15.904 square inches. The other thing would be to weld a 6" square piece of steel plate to the end of the pier. This would up the bearing area to 36 square inches. If you do weld a plate to the end of the pier, you should pour a shovelful of sand into the pier hole before you set the pier.

However, if the hole is properly backfilled, the lower end of the pier will transmit relatively little bearing pressure on the subgrade at the bottom of the hole. Practically all of the weight of the telescope, mounting and pier will be taken up by the friction between the backfill material and the outer surface of the pier. The situation is somewhat analogous to what happens when you try to cut a thick piece of cheese with a broad-bladed knife. As the edge, be it dull or sharp, cuts into the cheese, the adhesion between the cut surfaces of the cheese and the sides of the knife blade builds up. Eventually, these adhesive forces can become so strong that no amount of force can make the edge cut any deeper into the cheese. On the other hand, a taut wire easily cuts through the thickest cheese because these lateral forces cannot build up on the "sides" of the wire.

If you use the bare earth as a floor inside your observatory, or if you cover it with crushed stone or gravel, you should have no trouble with the pier picking up vibrations from foot traffic around the telescope. However, if you use a wood floor, make sure that none of the joists or sills have any direct contact with the pier. Wood floors laid on joists that rest on sills vibrate under foot traffic and you don't want any of those vibrations to get into the pier.

Earle F. Dodds
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Muscle Shoals, Ala. 35660

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formula for computing tolerances for zonal shift, therefore, we will not consider the effect of astigmatism and zonal irregularities. What we will do is to calculate the maximum knife-edge error allowable (i.e., the maximum zonal shift) from the zonal values calculated for a perfect paraboloid.

From the mathematical expressions for knife-edge (or zonal) shift and that for zonal height, we can derive a number of interesting statements about the properties of telescope mirrors.

Any two different-sized paraboloidal mirrors having the same focal ratio (or f/number) have crest heights (or departures from spherical form) which differ in the same ratio as the mirrors differ in size. The aberrations at the mean centers of curvature also differ in this same ratio.

Any two different-sized mirrors having the same focal ratio may — due to different degrees of parabolization — have equal zone heights and equal values of Δ R. Indeed, any two different-sized mirrors having the same focal ratio and zone heights — relative to a sphere — must have the same value of Δ R and equal aberrations as measured at their mean centers of curvature.

Any two different-sized mirrors having the same focal ratio and error of zone height — relative to that of a paraboloid — have equal errors of shift as related to their calculated values, and equal aberrations at the infinity focus of each.

Since zone height effects axial zonal aberrations independent of mirror size when focal ratios are equal, it's easy to construct a simplified formula for computing shift tolerances for any mirror — whatever its ratio may be. Thus, for a given standard of performance, (i.e. for given errors of zone height) we need to determine the allowable error of zonal aberration for a given focal ratio and then determine the effect of changes in the focal ratio.

The axial measurement of aberration for a given mirror size and zone height increases as the square of the image distance from the mirror. Proof of this is found when comparing a perfect sphere and paraboloid of equal diameters and radii of curvature — but for uses opposed to their nature. The axial spherical aberration of the one is only 1/4 as great as the axial aberration of the other at its mean center of curvature. Spherical aberration is determined by the formula $r^2/8F$, while paraboloidal aberration is determined by the formula r^2/R (not $r^2/2R$ which determines Δ R).

As a standard on which to base our calculations in setting up a simplified formula, we'll determine the allowable error of shift for a 10-inch f/5 mirror having 1/32 wavelength tolerance in the height of its intermediate (0.7071) zone. To do this, first we must determine the height of the paraboloid "donut" as measured from its reference sphere. The formula $r^4/8R^3$ is used — with r being 0.7071 x D/2 — and we find this height to be 0.00001953 inch, or 31.25/32 wavelengths. The shift for this paraboloid, 2 Δ R for the case of slit stationary and knife-edge moving, is found by using the formula r^2/R, and the tolerable error of shift is 1/31.25 of r^2/R. So, 1/31.25 x r^2/R = 1/31.25 x 25/100 =

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Amateur Astronomy in Milwaukee

Group Maintains Observatory for 40 Years

The serious pursuit of amateur astronomy began in Milwaukee with the appearance of the following notice on page 5 of the *Milwaukee Journal* of Sunday, September 18, 1932:

"Amateur star gazers plan an organization. Amateur students of heavenly bodies who are interested in organizing an amateur astronomical association have been asked to attend an organization meeting at 8 p.m. at the home of L.E. Armfield, 2046 S. 59th St., West Allis, Wisconsin."

The meeting went well: The Milwaukee Astronomical Society was formed as a result of it. There were 12 charter members.

As the Society approaches its fiftieth year of existence, its members have reason to feel proud. Through the years, the MAS has probably made as great a contribution to science as any other group in the world. With many of its members, astronomy is more than a mere hobby — it's an important part of daily life. And the knowlege that you've helped make a scientific contribution is very satisfying.

The newly formed group began regular meetings in the backyard of Mr. Luverne Armfield. They had a decent collection of their own telescopes — but no outstanding instruments. Major observing programs were observing meteors and variable stars. By 1933, the membership swelled to 100 (plus 30 more in the junior auxillary), and local interest in astronomy soared. The public library's section on astronomy increased by eight-fold. The number of telescopes owned by members expanded to 60. The members continued their observations of variables, as well as making height calculations of meteors. These observations were reduced by hand and sent to Flower and Cook Observatory in Upper Darby, Pennsylvania.

In 1934, Armfield, a long-time member of the AAVSO (his code being "A"), was offered the use of a 13-inch plate glass mirror. The offer (from the AAVSO via Harvard College) was made with the understanding that the society would have the use of it as long as they pursued the study of variable stars. That original mirror remained in use at the MAS Observatory until 1961, when a mirror of better figure was obtained. The old 13-inch was returned to the AAVSO.

That year also saw an offer of land to the Society. Professor M.J.W. Phillips, a member, donated an acre of land in Waukesha County, near the town of New Berlin, to the Society for an observatory. The land was to be held in joint tenancy with Carroll College, of which he was a graduate, so that the land would always be in use, even if the Society were no longer in existence. In March of that year, the MAS filed papers of incorporation and became a non-profit organization. Meanwhile, the 13-inch telescope was completed and put into use in Armfield's back yard.

1938: A group picture at the newly completed observatory. Left to right: L.E. Armfield, C.M. Prinslow, Mr. Heckencamp, Fr. Milton Lange, E.A. Halbach, Elisebeth Wight, Ray Cooke, Herb Grunewald, A.R. Ball, W.B. Albrecht, Ed Schoenke, Jack Schmidt, Earl Needham, John Ball, Jr., Rolland Mages, and Herbert Cornell.

1936: Meteor observing in the Society's early days.

1938: An aerial view of the MAS Observatory.

Twin highlights of the following year were the visit by Dr. Harlow Shapley to Armfield's house (Shapley spoke on Nova Herculis), and the formation of the American Amateur Astronomical Association, a joint idea of Armfield's and J. Wesley Simson. Simson was the editor of *Astronomical Discourse*, the publication of the Missouri-Southern Illinois Observers.

The development of the observatory site began in 1937 with the installation of an 8-inch reflector in a roll-off shelter. Ground was broken for the first observatory, the building that would later house the 13-inch. Work on the telescope progressed: a sidereal drive, setting circles, and slow motions in both axes were added. Local industry provided workmen to help with the dome fabrication and the members donated funds for the materials. In May of 1938, the 13-inch was installed; the dedication was on June 18 of that year. Cornelius M. Prinslow was appointed Observatory Director, responsible for distributing keys to the observing staff members and running the observatory properly.

Soon power was available: The group ran an electric line some 1500 feet from the neighboring Phillips farm. Shortly thereafter, a 250 watt radio transmitter was installed to coordinate the group's duplicate meteor observations.

Early in 1939, the society acquired a voting booth building. It served as an office as well as sleeping quarters for one shift of observers while another shift used the telescopes. Such dedication was not without hazards: Observer Ed Halbach dozed off while driving home after one late session and smashed into a light pole, injuring his leg.

In the years that followed, many projects and many observers passed through the Observatory — far too many, in fact, to list all of them in a brief article such as this one. Following are just a few of the highlights of each year's activity.

1940: Harvard College donates a Patrol Camera and the National Geographic Society gives the MAS two Kodak f/2 cameras for auroral photography. Hundreds of photographs of aurora were obtained with these cameras. The *Milwaukee Journal* donates a metal building which is used as a tool shed.

1942: Ed Halbach becomes Observatory Director.

1943: Gasoline rationing forces the suspension of observatory activities.

1944: Observatory shut down most of this year also; Halbach and Armfield set up an optical shop, making roof prisms at home for the government.

1945: The MAS conducts an expedition to Pine River, Manitoba, to tie the North American grid maps to the European grid maps. The expedition is sucessful. Mr. Ralph Buckstaff dontes his 12-inch reflector to the observatory.

1946: Member J.E. Willis develops the "Pendulum Astrolabe" for the Navy while

1937: Luverne Armfield breaking ground for the new observatory.

1934: Ed Halbach and the star charts used for variable star observations.

1934: L.E. Armfield's 13-inch reflector.

working for the David White Company.
1947: Ed Halbach is elected first president of the Astronomical League. William Albrecht and Halbach construct a prime focus camera for the telescope.
1948: The MAS begins a yearly contribution to the Kusiusko Fund in an effort to rebuild the famous Cracow, Poland observatory. Halbach heads an eclipse expedition to Burma, sponsored by the National Geographic Society. The group obtains 35 seconds of 35mm movie footage of the eclipse.
1949: Buckstaff telescope ("B") dome construction begins. Franklin Burr Award goes to Halbach for his efforts in Burma. Allis Chalmers installs solar radio receivers at the observatory.
1951: "B" dome completed, second telescope in operation.
1952: Halbach receives New York Astronomical Association award for services to amateur astronomy.
1954: Transit of Mercury successfully photographed. William Albrecht leads solar eclipse expedition to Mattice, Canada but is clouded out.
1955: Quonset building secured for the Society by the public museum. Annular eclipse expedition to Somalialand.
1957: Society joins "Moonwatch" satellite tracking program with immediate success.
1958: A.O. Smith Company donates $1700 toward the construction of a rotating shuttered satellite observation building.
1959: Pope and Osypowski obtain superb lunar and planetary photographs using "A" telescope.
1960-62: Continued work on satellite tracking, culminating in the visual observation of Sputnik 4 re-entry by Schaefer, Zit and Highsmith in September 1962.
1963: Society purchases two acres of land adjacent to observatory.
1965: MAS becomes a leader in the new field of grazing occultation work using trailer with 2 miles of cable for timings. Esterline Angus donates 20 pen recorder. Sanitary facilities added to the "A" building.
1966: Tom Pope leaves to work at New Mexico State University in planetary photography laboratory.
1970: Mirror grinding machine constructed to make 12 10-inch mirrors for "Portascope" telescopes for grazing occultation work.
1971: Drive installed on "B" telescope.
1972: Twelve MAS members observe total solar eclipse in eastern Canada; eighth eclipse expedition for Halbach.
1974: Graze telescopes finished. Halbach starts MAS on Eclipsing Binary Program to determine periodicity of EB stars.
1976: EB Program in full swing; MAS contributes 30% of world's total data for the program. Plans under way for 25-inch telescope. Halbach retires from observatory directorship.
1977: Nine observers obtain record graze results; 108 data points on region of limb near Cassini. Robert James is Observatory Director one year; Raymond Zit appointed new Observatory Director.
1978: Fund drive under way for 25-inch telescope project; work begins near end of year.

The importance of a stable, long-lasting astronomical society for encouraging observing and telescope making cannot be underestimated: It provides a center for exchange of ideas and information; it provides examples of excellence; and it provides the advantages of cooperative effort. We hope that the MAS will continue to provide these benefits to amateur astronomers in the Milwaukee area for a long time to come.

Raymond E. Zit, Observatory Director
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short comparison of properties (from memory unfortunately) is below:

Property	*Pyrex*	*Silicon Nitride*
Tensile strength (25°C)	*15,000*	*140,000 psi*
Compressive strength (uniaxial)	*150,000*	*500,000 psi*
Young's Modulus (stiffness)	*$10x10^6$*	*$40x10^6$ psi*
Thermal coeff of expansion	*$5x10^{-6}$/°C*	*$3x10^{-3}$/°C*

Let me point out, for the record, that I have nothing to do with my company's marketing staff, but am interested only in getting some dialogue going on these materials. The silicon nitride material is currently obtainable in disks up to 15" diameter, but other ceramics with similar properties can be had up to 30" wide. Sufficient stiffness for an optical blank could be had in pieces only 3/8" thick — a 15" blank could potentially weigh only 8 pounds! Even thinner blanks might be possible, but I'd have do some work on it. The material is inert in an air environment up to 700°C, and chemically inert at room temperature to everything except HF. It's extremely hard (cuts glass easily) and can only be damaged by SiC, diamond, and cemented WC. As a result, it is difficult to machine with anything except diamond. The surfaces on the sample I've sent you are 200 grit diamond surface ground and probably about 10 to 15 microns rough. Diamond lapping or honing followed by CeO_2 or SnO polish results in highly reflective surfaces.

Another material of interest may be an extremely fine-grained Si/SiC composite. This material has about 20 percent silicon metal incorporated which, when diamond lapped, gives an essentially metallic reflective surface. It is not as strong as silicon nitride, but it is still considerably stronger than Pyrex. It has a lower density than Pyrex (2.9gm/cm^3) and is available in plates up to 20" diameter.

I'd be glad to hear from you or any other competent, interested party who would like more details on any of these materials.

J. W. Lucek
R&D M6-5
Norton Company
Worcester, Mass. 01506

Subsequent telephone conversation with Mr. Lucek revealed that these fantastic space-age materials are expensive — $800 for an 8-inch disk. But I think I've seen a bit of what's coming for the next century's space telescopes, and I'm very impressed with the little bar of silicon nitride that he sent. It is very hard stuff, and makes a great glass cutter!

R. L. B.

Errata

TM1, "Cassegrain Optical Systems," page 10, equation 5a should read:
Primary: K = (equation) = 0.2929687-1
= 0.707
Equation 7a should read:
Primary: K = (equation) = -1.041666...
(the minus sign was missing).
Finally, page 12, left column, line 10 should read figure 4 instead of figure 3.

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0.008 inch. (When slit and knife move together, the shift is Δ R, and the tolerance is 0.004 inch.)

But why have we given the height of the paraboloid "donut" in terms of 1/32 of a wavelength? To obtain a 1/4-wave correction at the telescope's focus, the tolerance in crest height is 1/32 wavelength. Thus the crest height may be given as 31.25/32 plus or minus 1/32 wavelength. Since 1/31.25 of the crest height is the allowable error, it follows that 1/31.25 of the knife-edge shift is allowable error — either plus or minus.

You can convert waves into actual glass on the mirror if you know the wavelength — in this case choosen as 0.000020 inches, or 508 Angstroms, largely for reasons of numerical convenience.

The shift tolerance at the mean radius of curvature of an f/5 paraboloid of any diameter is determined to be plus or minus 0.008 inch (or .004 inch when the slit and knife-edge are moved together) for an aspheric error tolerance on the glass of 1/32 wavelength as measured at the 0.7071 zone.

When making a spherical mirror of the same focal ratio — with a tolerance of 1/32 wavelength for aspheric error as already described, the zonal shift must not exceed 0.008 inch, or Δ R must not exceed 0.004 inch.

The shift tolerance at the infinity focus (that is, performing the knife-edge test on a star image or via autocollimation) of a 10-inch f/5 paraboloid having 1/32 wavelength accuracy is determined by dividing the value of $r^2/8F$ by 31.25. The result is 0.002 inch. If you test by using autocollimation, where the light is twice reflected from the paraboloid, the shift tolerance is increased to 0.004 inch. If you test by using autocollimation with the light source and knife-edge moving together, the shift tolerance reverts back to 0.002 inch.

From the rules and formulae discussed above, you can derive the following formula for shift tolerance determination:

$$S = kN^2d$$

Here N equals the length of the light cone divided by the aperture or base of the cone, d equals the tolerance in "donut" height in wavelengths of light, k is a constant we'll discuss below, and S equals the shift tolerance in inches. It provides the means for rapidly computing zonal shift tolerances for any size and focal ratio of mirror, and for any conjugate focal position where the knife-edge may be placed to measure aberration.

The number k equals 0.00256 when the light source is fixed and only the knife-edge is moved along the optical axis. When the light source and knife-edge move together, k = 0.00128.

When testing by autocollimation, k = 0.00512 when only the knife-edge is moved. When slit and knife are moved together, k = 0.00256.

As an example of a simplified computation using the above formula, the shift tolerance at infinity focus for a 10-inch f/5 mirror is determined as follows:

$$S = 5^2 \times 1/32 \times .00256 = .002$$

For the longer cone terminating at the mean center of curvature (the ordinary Foucault test) we have:

$$S = 10^2 \times 1/32 \times .00256 = .008$$

SHIFT TOLERANCE TABLE

N	k = .00128	k = .00256	k = .00512
3	0.000	0.001	0.001
4	0.001	0.001	0.003
5	0.001	0.002	0.004
6	0.001	0.003	0.006
7	0.002	0.004	0.008
8	0.003	0.005	0.010
9	0.003	0.006	0.013
10	0.004	0.008	0.016
11	0.005	0.010	0.019
12	0.006	0.012	0.023
13	0.007	0.014	0.027
14	0.008	0.016	0.031
15	0.009	0.018	0.036
16	0.010	0.020	0.041
17	0.012	0.023	0.046
18	0.013	0.026	0.052
19	0.014	0.029	0.058
20	0.016	0.032	0.064

Note that the latter calculation results in a figure that is four times greater than the first one.

You can make a table quite easily to read off the shift tolerance for various mirrors. Remember that N is not the f/number of the mirror, but the image distance divided by the aperture. A mirror rated as f/8 at its infinity focus produces a cone of light equivalent to N = 16 in a test at the mirror's center of curvature.

Let's apply the table below in an example to check how it operates. The 10-inch f/5 mirror (at its focus) from the table shows a shift tolerance of 0.002 inch in agreement with the formula. At the center of curvature, N = 10, and the table shift tolerance of 0.008 inch again agrees.

If a mirror doesn't have an exact f/number, say f/4.6, then you can find the shift tolerance by the formula, but it's always safe to use the next lower figure, in this case for the N = 9 value.

When you measure a residual shift difference and wish to know the correction in terms of wavelength, then exchange the S and d in the original formula to obtain the new formula:

$$d = S/kN^2$$

For example, if our 10-inch f/5 mirror has a residual shift of 0.002 inch, what is the correction?

$$d = .002/(0.00256 \times 5^2) = 1/32$$

— a correction of 1/32 wavelength!

This formula has been used for over 18 years in testing and evaluating optics in professional shops. It's important to remember that the shift measurement should be made at the 71 percent zone, or 0.7071 of the radius of the glass surface. Remember also that it applies to smooth departures from a proper figure, and is not recommended for irregular and zoned surfaces.

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